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MAN'S PHYSICAL UNIVERSE

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A Survey of Physical Science for Colleges

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PREFACE

MOTIF

> If civilization is to be worth what it has cost in effort and struggle, if the vast accumulation of knowledge and power which our age has come to possess is to be directed toward ends of general human advance, there must be a great and rapid increase in the number of persons who possess the spirit and attitudes of liberal and cultural education. — Adapted from Everett Dean Martin by Benj. F. Shambaugh.

This book is intended to be used as a text for survey courses in physical science. Dr. B. L. Johnson of Stephens College defines a "survey course" as one "which cuts across two or more departmental fields and which has as its aims, (1) to give the student an over-view of the fields concerned, and an understanding of their principles and relationships, which will be most useful to him as a member of society, (2) to aid the student in determining whether he wishes to specialize in any aspect of the field."

This text is intended for use in a program of general or liberal education. The idea of general education is not merely an academic fad. It represents a clear-cut difference in educational theory.

General education is not a selective rejecting process that permits only the upper 10 per cent to pass through its aristocratic sieve. It is based on the idea that every student is educable, in some fashion or form, and that it is possible to find out how to help him.

Dr. A. D. Laton has said, "We are interested in the kind of learning which will be consistent with the sum total of human knowledge, and will lead to adaptive action in the fields of human activity."

General education seeks to push forward the development of a good life. The educational experience which it provides is rich to the extent that it deals with the problems of life today.

Briefly, this course is designed to bring from the archives of physical science the most important facts and generalizations which have any bearing on these problems. I have attempted to survey the phenomena of the physical universe with particular reference to man's immediate environment, to present a knowledge of the vast and only partially explored setting of our civilization, to envisage the great problems of

the origin and evolution of the universe and the relation of man to the universe, to review briefly the present status of the nature and distribution of the resources which supply human needs and man's ability to utilize them, and to show how man is gaining control over the forces of nature and harnessing them to do his work.

I have attempted to explain the more important principles and the relationships which have been found to aid in an understanding of them. Continuity and panoramic completeness have been attempted by integrating the material both with problems and principles, as well as by the historical approach. Breadth is striven for, rather than depth. I have attempted to present much more than mere "tidbits" of knowledge.

A great neurologist showed me how he did his work. In the study of the brain he first prepared very thin slices which he could study in minute detail under the microscope. After making these studies his next great task was to trace the relationships from one slice to another, and not until he did this could he arrive at any meaning in his work. Science has done a beautiful job in preparing individual slices of knowledge; but until these slices are fitted together to form a whole again, they will have little meaning. It is the purpose of the survey course to try to fit these slices together and to discover a pattern running through all of the sciences that will provide not only intelligible but useful knowledge.

It has been one of my great concerns that the student be led to develop open, critical, and cultural attitudes of mind that will lead him to attempt to use the scientific method in solving the important problems of life.

A large portion of the class periods in the author's course in which the text is used are devoted to visual aids and lecture demonstrations which supply the experimental data needed to complete the scientific approach. Lack of space made it necessary in many cases to present theories or generalizations without referring to the experimental data on which they were based. Teachers should keep in mind that one of their main functions is to present this experimental material. A few well-chosen experiments will be found to be much more convincing than thousands of words telling about them.

I recognize how far short of my goal I have fallen, but I have made an honest attempt and now place the results of my labors in your hands, hoping that I will receive much helpful criticism.

I do not apologize for including some discussions of the social consequences of the development of physical science. The material presented must have meaning to be of lasting value, and meaning is

essentially socio-centric. The objectives of general education require that we raise such questions as "What are the consequences?" and "What difference does it make, or is it making?"

The text often savors of dogmatism; but this is the price to be paid for the conciseness and clearness which I have attempted. I have no doubt that a purist will be able to find statements in this book which require qualification or extension. Some of these shortcomings may have crept in through inadvertence or ignorance, but others are inherent in the method of presentation. For, while I have wanted to be accurate, I have been even more desirous of being understood.

This book is not intended for "snap" courses, but it has been "de-technicalized" as far as possible. I have taken Dr. Paul Monroe's definition of a high-standard course for my own: "A high standard course is one which stimulates its students to further self-propelled study in its field."

Well-known trade names and some of the important manufacturing companies of the United States have been deliberately referred to, in spite of the fact that many teachers will feel that this text is thus "contaminated by advertising" and at the risk of displeasing these and other manufacturers whose products I may have overlooked. This text is designed to show the relation between Science and modern technology in the United States and to present information which will be of practical value to the student. Furthermore, I believe that credit should be given where credit is due, and no one should discount the tremendous contributions of many industrial research laboratories to the treasure-house of Science as well as to more abundant living.

This text is divided into units and sections for pedagogical reasons. Each section is intended to be used as the assignment for one lesson and constitutes a complete topic in itself. If one section is assigned for each day, with the exception of a few days reserved for hour examinations over the units, it will be found that a course which meets three times a week during the year or five times a week during a half-year will be able to cover the material presented. I shall be glad to offer suggestions concerning the selection of Units and Sections for shorter courses to teachers who send for such suggestions.

Survey courses must not submerge the individual. Some method must be found to provide for individual differences as a part of the technique of handling large groups of students, which is so often necessary in these days when so many young people come to college seeking a general education. I have solved this problem in part by allowing the students to read current magazine articles and books,

which the student selects according to his interests usually after conference with the instructor. In my classes the students write a paper for each unit, based on outside readings related to the subject matter in the unit. Many of the books listed in the Appendix are available to my students, and I believe that they constitute one of the most valuable features of the course. Specific references are not given for each section, but the books have been grouped in part according to the units with which they are most closely related. The student is encouraged to use the *Reader's Guide* and other sources of information in locating magazine articles.

ARTHUR T. BAWDEN

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ACKNOWLEDGMENTS

Every section in this text was criticized by at least five competent experts. The majority of the sections were criticized by from two to four additional readers. Many industrial organizations have made major contributions in the form of criticisms and illustrations. I have already personally thanked these individuals and organizations for the invaluable help which they have given me in preparing this second edition of *Man's Physical Universe.*

I have decided not to list the names of the many people who have contributed to the improvement of this book, not because I am not deeply grateful to them for their help, but because I do not want them to be held responsible in any way for inaccuracies and inadequacies which cannot be avoided in presenting a comprehensive and panoramic picture of the physical sciences.

Our indebtedness to many sources of material is apparent. In such a wide field, no claim to originality can be made. The reader who is familiar with the references listed in the Bibliography will recognize many general influences. Many passages are the development of ideas whose origin I have forgotten, but I have been careful to acknowledge all quotations taken from copyrighted sources. I am sure that my readers will join me in expressing my thanks to the authors and publishers of such passages for their generosity in allowing me to incorporate their ideas clothed in their own language.

It is a pleasure to acknowledge my indebtedness to the many teachers and students whose criticism of the First Edition of this text has guided me in the preparation of this Second Edition.

ARTHUR T. BAWDEN

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MAN'S PHYSICAL UNIVERSE

INTRODUCTION

> Indulge your passion for science, says nature, but let your science be human, and such as may have a direct reference to action and society. . . . Be a philosopher; but, amidst all your philosophy, be still a man. — Hume.

The Goal of Humanity Is the More Abundant Life.

Although some people have no goal at all and others seem to be working at cross-purposes, there are many who agree that satisfaction is the goal of humanity.

Satisfaction is not the same as pleasure or happiness, though ordinarily these things go together. Satisfaction is not mere sluggish contentment. It is something we have to work for, and our efforts must have some measure of success to be satisfying. Some successful adventures yield more satisfaction than others, and usually the best things cost the most effort. So it is important to regulate our wants judiciously, to use intelligent foresight in selecting the things for which we work the hardest, and to get all the help we can in pushing on toward the chosen goal. In the advancement of this program natural forces have been harnessed in the service of man, and social institutions have been organized for more efficient teamwork.

Successful use of natural resources and of social opportunities depends on knowledge about these things and either some measure of control over them or else intelligent adjustment of the individual to them. The acquisition of knowledge and active adjustment broaden experience and make life richer. This more abundant life brings wider and higher satisfactions.

As society is now organized, nobody can live by and for himself alone because his own welfare is bound up with that of the community in which he lives. Accordingly, our finest satisfactions arise within the social adjustments, and the greatest happiness comes from maintaining right relations with our fellow-men; the right relations are those which are mutually beneficial.

In so far as man devotes his life to the betterment of mankind to the best of his ability, he is fulfilling his purpose in life. Thus, today, more than ever before, man values preparation for life, and young people are going to colleges in ever increasing numbers to obtain this preparation.

The Scientific Attitude and Method Are Essential to the Attainment of the Goal of Humanity.

It has just been pointed out that to get satisfaction we must give something. Selfishness must be tempered with unselfishness. In our social organization the only way to reach the goal of personal happiness is by directing our major efforts toward the higher goal of general welfare, the Goal of Humanity. This implies service for the general good; and good intentions for service, although they are absolutely essential, will not take us far without the knowledge of how to carry them out.

Knowledge of mankind, knowledge of one's self, knowledge of one's physical environment — every kind of knowledge is essential to progress. Knowledge is most effective when it is organized. "Science" has frequently been defined as "organized knowledge and the method by which it is obtained." The method by which knowledge is obtained is the chief characteristic of Science. Briefly, it is the appeal to experience rather than to traditional dogmas or to any authority not supported by controlled experience. The scientific method is the expression of an attitude of faith in the Order of Nature as revealed through human experience. Inasmuch as naïve experience is always limited and often untrustworthy, the scientific method involves the control of every experience by verification by experiment; cultivation of accuracy of observation, careful keeping of records, and logical analysis of the congruence of every experience with other experiences are likewise involved in the scientific method.

Progress in the discovery and utilization of *knowledge requires a more general acceptance of the scientific attitude and a more widespread use of the scientific method.* Such progress, together with an increased desire for the general welfare, is essential to the attainment of the Goal of Humanity.

UNIT I

THE INTELLIGENT SOLUTION OF PROBLEMS AS THEY ARISE IS THE PRICE OF LIBERTY

INTRODUCTION TO UNIT I

> The acquisition and systematizing of positive knowledge is the only human activity which is truly cumulative and progressive. Our civilization is essentially different from earlier ones, because our knowledge of the world and of ourselves is deeper, more precise and more certain, because we have gradually learned to disentangle the forces of nature, and because we have contrived, by strict obedience to their laws, to capture them and to divert them to the gratification of our own needs.[1] — Sarton.

Man alone, of all the animals, has the ability to evaluate his own experiences. He alone has the power of directing his behavior, of guiding it by what he has learned from past experience, although his efforts are pitifully inadequate.

At last, man has developed a method of thinking and an attitude of mind that can lead surely and ever more rapidly to progress.

In this unit you will be introduced to this attitude and method. You are hereby warned that you are now entering upon a study that will probably revolutionise your thinking and greatly change your conduct for the rest of your life. If you are not ready for such a change, *stop here*, for what follows is not for you.

Professor Walter M. Kotschnig wrote in *The Harvard Educational Review*,

> Putting it bluntly it is this: much of our teaching at home and in the schools of this country has tended to undermine and destroy the sense of values of the younger generation and to leave them naked in a world of predatory animals; worse, to turn them into predatory animals themselves. . . . This is the world in which we live . . . a world without values.

Professor A. J. Carlson ("Is This the Age of Science?" *Sigma Xi Quarterly*, winter, 1940) points out that we are living in an age of propaganda in which lying is a fine art, although

> the scientific method demands that we suspend judgment until we know the facts and demands honesty, integrity and industry in ascertaining the facts.

[1] *Introduction to the History of Science*, Vol. I, pp. 3–4.

He also points out that the shops of astrologers and fortunetellers had as great an attendance as did the Adler Planetarium at the Century of Progress Exposition, and that many people neglect and oppose vaccination, thus delaying the wiping-out of smallpox, although there is nothing better substantiated than the effectiveness of vaccination against smallpox. He concludes his thesis that this is not an age of Science by showing that increased knowledge is used by society largely to " satisfy greed, lust, hate and vanity" because the spirit and method of Science have not appreciably influenced the average man.

The present world-upheavals demonstrate what happens when predatory men are given the power which modern scientific knowledge has set free. Democracy can be a bulwark of civilization only to the extent that it is influenced by the scientific attitude and utilizes the scientific method in the solution of problems in terms of basic, time-tested values; in fact, the price of liberty is the intelligent solving of each problem as it arises in daily life.

UNIT I

SECTION 1

PROBLEM-SOLVING ABILITY IS ONE OF THE MOST IMPORTANT AIMS OF EDUCATION IN A DEMOCRACY

Introduction.

One of the reasons that dictatorships exist is because so many people believe that the major problems of society cannot be solved by democratic processes.

In totalitarian states, people are taught what to think rather than how to think. In such states the dictators and the subleaders under them do the thinking and the planning for the rest of the people, who are forbidden to think. "Theirs not to reason why. Theirs but to do and die."

In a democracy problems must be settled privately, or by cooperative enterprises, or by representatives selected by the people to solve problems in accordance with the will of the majority. In a democracy problems cannot be solved by a dictator, benevolent or otherwise. Since every citizen is *his own dictator* in a democracy, *success in meeting human needs depends upon the extent to which the masses have mastered the techniques of solving problems.*

New Problems Arise in a Period of Cultural Transition.

Culture Is the Way a Society Does Things. How our society does things depends upon our geographic environment, our cultural heritage, and the creative activities of man. Changes in culture come chiefly as a result of man's activities. A certain amount of change would be found in any culture because the knowledge of the past is influenced by the men to whom it is entrusted as it is handed down from one generation to the next. The most important causes of cultural change are the contacts between different cultures and inventions within the group. The greatly improved modern methods of transportation and communication have increased the contacts between modern cultures. Each invention leads to other new inventions. Modern Science has greatly accelerated the rate of producing epoch-

making inventions largely as a result of a wider application of the scientific method, *i.e.*, the techniques of solving problems.

The following data illustrate this point:

PATENTS ISSUED BY THE UNITED STATES PATENT OFFICE

NUMBER OF PATENTS ISSUED

YEAR	NUMBER
1840	458
1860	4,363
1880	12,926
1900	24,660
1920	37,164
1940	42,248

In a period of rapid cultural change there is often a struggle between conflicting interests, which leads to a condition of social strains somewhat analogous to those set up by the rapid and unequal heating or cooling of glass. The introduction of the steamboat was fought by owners of sailing vessels just as the growth of modern highway transportation has been fought by the electric and steam railroads. Every important new invention, such as the modern cotton-picking machine, creates new jobs and at the same time throws other people out of work. You are living in a period of rapid cultural change in which *new problems are continually arising.*

Problem-solving Technique Is Important for the Success of Democracy.

There are many indications that we have reached a very critical point in our cultural change, in which *pressing problems must be solved to avoid a cultural upheaval.*

Modern specialization, because it brings interdependence, requires cooperation and centralized controls. How can the individual in a democracy maintain control of the centralized planning and coordination required to solve the problems of distribution of the products of modern industry?

If large numbers of individuals are unable to satisfy their basic needs and arrive at the conclusion that individuals in a democracy can do nothing to solve their problems, their emotional frustration will cause them to follow any leader who promises a solution even if it leads to violence and subservience.

The rank and file, as well as the leaders of organized labor, business, religion, farming, teaching, and distribution, *must know how to think in the modern scientific manner*, which eliminates prejudice, and how to recognize propaganda, if *dictatorship, violence, untruth, brutality, and intolerance are to be kept out of democracies.*

Unsolved Problems Lead to Frustration.

Almost everything we do is done about a problem. We eat and sleep to satisfy needs, but improper food or sleep may fail to meet these needs satisfactorily; and disease, pain, unhappiness, even suicide, result. We go to school to satisfy basic needs, and yet school does more harm than good to many people. We marry to satisfy human needs, but a large number of people find that their marriages have been failures. We buy many products to satisfy needs and then discover that they were misrepresented or that we did not need them after all.

We are solving problems every day; but because we have not learned the scientific techniques of solving problems, our solutions to these problems are often very unsatisfactory. Just as students do not always obtain the correct answers in solving arithmetic problems, so everyone gets the wrong answers to some problems. Wrong answers lead to *failure.* Right answers lead to *success.*

Problem-solving Ability Is a Measure of One's Intelligence.

Adaptation is conformity to a need. The ability to quickly adapt one's self to a changed situation requires problem-solving ability. There are many different kinds of problems, and, therefore, there are many different types of problem-solving ability. Some people can solve mechanical problems best, while other people can solve social problems best. Regardless of whether one is an automobile mechanic or a physician, he needs to be intelligent. The intelligent person selects problems which he knows how to solve. The technique of solving problems scientifically can be learned by everyone. That technique is discussed in Section 3 of this Unit. Please note that *the two most important objectives of this text are: first, to help you to learn how to solve problems, and second, to help you to discover the types of problems which you are best able to solve.*

Mental Growth Results from the Solution of Problems.

Problem-solving does not have much influence upon subsequent behavior unless one's experience fits into an existing pattern in such a way as to make the next step toward the goal more definite. Goals constitute one of the best integrating factors available to give meaning to experience.

Isolated knowledge is equivalent to meaningless experience. Matter which has a definite plan of organization or logical sequence is learned most rapidly.

Mental growth results from one's own act of integrating and organizing knowledge. This text has been designed to help you to develop a

pattern for the organization of knowledge concerning the physical universe. The author has done his part to the best of his ability. It remains for you, the student, to select one or more of the objectives of this text listed in the next paragraph. If none of these goals are *your* goals, it is probable that you have made a mistake in selecting this course of study.

The objectives of this course are:

1. *To help the student to formulate worthy goals and to choose ideals which will form a sound basis for discriminating judgment.*
2. *To develop such an understanding and appreciation of the scientific attitude that the student will actively cultivate it,* thus liberating him from superstition and fears and giving a sound basis for successful adjustment.
3. *To provide an understanding of the nature of the scientific method and to instil the habit of using it to solve the problems of life.*
4. *To impart an understanding and appreciation of the nature of the universe and man's relation to it;* in other words, to help the student to develop a wholesome philosophy of life.
5. *To afford an appreciation of the work and contributions of great scientists.*
6. *To provide a background of information essential to the solution of the problems of modern life as revealed by physical science,* to the end that everyone will be able to interpret the phenomena of his own everyday experience in an intelligent, satisfying manner and live more effectively in the new environment created by physical science. Facts are the basic materials of thought; this course seeks to give a broad foundation of the most important facts of the physical sciences.
7. *To survey and integrate the important generalizations of physical science* in order to give meaning to the facts learned.
8. *To show how physical science is changing the life and thought of man,* showing particularly how physical science has enabled man better to adapt himself to his physical environment.
9. *To provide guidance for the student by outlining the scope and the content of the different physical sciences,* to enable him to determine whether or not his interests and talents lie in any one of these fields of knowledge, and if they do, to stimulate further studies in physical science.
10. *To make clear the relation of the various sciences to each other.*
11. *To enable the student to develop a taste for the current nontechnical scientific literature and to acquire a vocabulary adequate for an understanding of it. Well-equipped travelers in this scientific age* require a certain minimum scientific vocabulary. "He that travelleth into a country before he hath some entrance into the language, goeth to school, and not to travel." — Francis Bacon.
12. *To provide a broad background for future specialization.* In the words of A. N. Whitehead, "Wisdom is the fruit of a balanced development." We are living in the age of specialists. Specialization,

however essential in obtaining knowledge, is exceedingly dangerous if allowed to lead to an unbalanced development. Someone has said that "the specialist is one who is learning more and more about less and less, until he eventually knows everything about nothing." It is important that one should gain an understanding and appreciation of the character of the universe as a totality before he begins to specialize, so that he will not lose his sense of values in his later specialization and thus become "an educated fool."

13. *To develop new interests and an intellectual curiosity.* Richness of life is measured by one's alertness and breadth of interest.
14. *To educate the student to know the satisfaction of work well done, to appreciate the social value of his work, to develop standards for guiding his expenditures, to have a regard for natural resources, and to measure technical advances in terms of the general welfare.*

SUMMARY

1. Science, through invention, has caused important and rapid changes in our culture and has thus created many problems.

2. These problems must be solved to avoid violent revolution and the overthrow of democracy. Violent revolution is a way of solving problems, though it is a painful way, and sometimes the solution is worse than the problem. Democracy provides the machinery for solving problems peacefully. Whether that machinery is used or not depends in part upon us.

3. Personal happiness likewise depends upon the solution of problems.

4. The ability to solve problems, *i.e.*, the scientific method, is the most important contribution of education to the individuals in a democracy.

Special Assignment.

Instead of the usual study questions, the author suggests that you carefully consider which of the following courses of action you think will help to develop your ability to solve problems. It is exceedingly important that you have conferences with your teacher as often as possible in order to obtain suggestions and help on the projects selected.

SUGGESTED COURSES OF ACTION

1. Take tests to determine the particular weaknesses which need improvement.
2. Solve real problems under the guidance of your teacher, starting with simple ones. See the problems listed at the end of Section 4.
3. Read books on "Problem-solving" and "The Scientific Method." See the Bibliography for Unit I, at the rear of the book.
4. Read books on "Consumers' Economics."

5. Prepare papers on "The Evaluation of Advertising in Various Fields."
6. Work on special exercises to develop alertness in observation.
7. Study the lives of people who have been successful in solving problems. See the Biography Section of the Bibliography, for Unit I.
8. Try to discover why people you have known have failed to achieve success.
9. Develop the scientific attitude by reading the *Life of Pasteur* by Vallery-Radot or *Discovery* by Sir Richard Gregory. See the Bibliography.
10. Prepare a list of color words and check those to which you react emotionally.
11. Read *Do You Believe It?* by Caldwell and Lundeen, and "How to Think Straight" by Thouless. See the Bibliography.
12. Prepare one or more term papers on such topics as the following:
    Astrology, a Pseudo-science?
    How to Recognize Propaganda
    Truth in Advertising
    Einstein — Scientist and Philosopher
    The Scientific Attitude and Early Education
    Should Research be Conducted by Public or Private Institutions?
    The World's Ten Greatest Living Physical Scientists
    How Can the Consumer Buy Intelligently?
    The Scientific Attitude
    Galileo — A Scientific Pioneer
    The Contributions of the Ancient Greeks to Modern Science
    Important Inventions in Any Ten-year Period
    The Scientific Method in Daily Living
    Advances in Science in Any Ten-year Period

UNIT I

SECTION 2

THE SCIENTIFIC ATTITUDE IS ESSENTIAL TO THE SATISFACTORY SOLUTION OF PROBLEMS

The future of our civilization depends upon the widening spread and deepening hold of the scientific habit of mind. — John Dewey.

Introduction.

At about 8:20 Sunday evening, October 30, 1938, the traffic on highways between New York City and Philadelphia suddenly went wild. Cars speeded past traffic patrolmen as if to escape a tornado. Telephone exchanges were swamped. It was all due to a realistic radio broadcast of an imaginary invasion of the earth by armed monsters from Mars. According to the Gallup poll nearly 20 per cent of the nine million people who heard this broadcast were frightened.

Dr. Hadley Cantril found from a factual study of "The Invasion from Mars" that persons who were *frightened* by the broadcast believed what they heard without making any effort to check the reasonableness or reliability of the report. He concluded in part that "Our study of the common man of our times has shown us that his ability to orient himself appropriately in critical situations will be increased if he can be taught to adopt an attitude of readiness to question the interpretations he hears."

These people who were so quick to give way to useless fear at the expense of reason were those same people who previously prized certitude and feared knowledge. They had not developed the scientific attitude which asks "Is it so?"

Perhaps you would not be frightened by a radio broadcast, but do you buy your soap, hair tonic, cigarettes, or breakfast food on the basis of the radio announcer's advice? Do you believe that a thing is true just because it is printed? Do you buy without investigation? Do you select professional services upon the mere recommendations of others? Do you have the "I am from Missouri; you have got to show me" attitude?

The Scientific Attitude Is the Truth-seeking Attitude.

Science is an activity where honesty is most obviously an essential condition for success. "In nearly everything else truth is a means, not an end. An advertisement may tell lies, but then telling the truth is not its object. Its object is to sell the stuff, which is an entirely different object." [1]

An attitude is simply a habitual way of looking at things, or a state of mind. It is largely emotional in nature and motivates and determines conduct and behavior. The scientific attitude causes one to seek to control primitive emotions by rational appeal to fact rather than by superstitions, prejudices, traditions, customs, precedents, dogma, and intolerant self-conceit.

Why Should One Desire to Know the Truth?

1. ***The Quest for Truth Is One of the Most Valuable Activities of Mankind.*** Truth is one of the values whose pursuit leads to life's greatest satisfactions.

2. ***Human Progress Has Been Most Rapid When the Search for Truth Has Been Conducted Scientifically.*** Today the lame walk, the blind see, the naked are clothed, and the hungry are fed because of the knowledge that man has attained.

3. ***The Search for Truth Liberates Man from Stultifying Influences.*** Science has removed the fear of unseen demons which lurked behind every rock, tree, and lightning flash for primitive man. Science liberates us from the oppression of superstition and intolerance and the penalties of ignorance. Science may indeed bring freedom to mankind. "Ye shall know the truth, and the truth shall make you free." (John 8:32)

Within our own generation we have seen many whole nations enslaved by men who do not accept truth as a value. We have seen other whole nations of people willing to die rather than give up their hard-won freedom to seek the truth.

The Truth Seeker Must Cultivate Certain Habits of Mind.

The easiest way, perhaps the only way, to see how Science works is to see how scientists work. Scientists are not supermen. They are quite ordinary-looking people such as you might see anywhere. The scientist is interested in the same things as other people, but his interest is exercised in a special way, which we shall now describe.

1. ***He Realizes That Truth as Discovered by Man Is Never Absolute.*** The truth seeker cannot hope to discover finality in a universe in which

[1] J. W. N. Sullivan, *The Limitations of Science*, The Viking Press, 1934, pp. 276–277.

change is one of the dominant characteristics. Every investigation soon runs up against a wall of ignorance which, once surmounted, enables one to see a still higher wall in the distance. The quest for truth is endless, and no human problem is ever finally settled. The best that one can do is to reach a tentative conclusion based on all the data available. The realization that truth as we know it is neither absolute nor complete is one of the most self-purifying attributes of the truth seeker

FIG. 1. Pithecanthropus Erectus could not understand. Primitive man displayed his reverential awe of Nature's Forces by fearful apprehension. As intelligent familiarity developed, man learned that these phenomena were not capricious . . . but obeyed rigid laws that could be recognized and cataloged . . . he learned that some of these forces could be harnessed and put to work. (Courtesy of The Sharples Corporation.)

because it keeps him from becoming conceited, opinionated, or dogmatic. It keeps him humble because he measures what he knows beside what remains to be discovered. It spurs him on to renewed effort. The truth seeker feels that the very best that he has to offer is all too little when he sees on every hand the sufferings of mankind which are the results of problems unsolved or inadequately solved.

2. He Believes in the Orderliness of Natural Processes. The truth seeker does not believe that events happen capriciously, nor does he believe in magic, astrology, fortunetelling, or "lady luck." The student of nature soon discovers that our universe is one of law and order. He knows that cabbage seeds produce cabbages rather than sunflowers. He realizes that nature makes no exceptions for any individual and that

the only changes which he can bring about are those which are in conformity with the laws of the universe. He learns that behind every result there is an adequate cause and that the same causes will always produce the same results.

3. He Is Curious. The truth seeker is definitely curious about cause and effect in the world in which he lives. He is interested in everything that happens. He realizes his ignorance and seeks to know. He is not complacent or indifferent to personal and social needs. He is never a disinterested bystander, but his curiosity is impersonal and disciplined because desire must be subordinated to reason.

4. He Is Open-minded and Unprejudiced. The truth seeker has seen in our own generation how violent, unreasoned prejudice, class and personal hatred, and insane fear bear frightful fruits of death, destruction, and persecution. He does not want merely to obtain support for his preconceived notions — he wants to know the truth about the natural world, about politics, business, and morals, in short, about life. He is willing to lay aside lifelong convictions, the traditions of history, the morals and customs of his social class long enough to see whether or not a new fact will change his point of view. He never laughs at new ideas. Indeed, he distrusts his own feelings and, at times, refuses to believe the evidence of his own senses because he realizes their deficiencies and the possibilities of error. The truth seeker welcomes new ideas, especially those with which he is not now in agreement.

5. He Is Aggressively Tolerant. The truth seeker must be ready to admit that other people may know more than he does and that they may be right and that he may be wrong. But his tolerance will not extend so far as accepting other people's ideas unless the evidence at hand supports these ideas. He seeks to discover the elements of agreement and disagreement between himself and others in an effort to increase his knowledge.

The truth seeker does not ask others to accept his own point of view.

Where the scientific attitude reigns, there is no regard for party, race, creed, or nation. Thus Marconi, an Italian, devised the wireless telegraph which was based on the researches of Hertz, a German, who, in turn, got his inspiration from Maxwell, a Scot.

6. He Does Not Accept Conclusions unless They Are Supported by Adequate Evidence. The truth seeker is definitely skeptical. Skepticism is not cynicism or suspicion, but it does involve the scrutiny of every belief, custom, and conclusion to discover the data, if any, upon which it rests.

Anyone who wants to solve problems should first develop skepticism, for unless he is very critical of all of the information which he obtains,

he may accept some of it without verification and checking and thus be led to faulty conclusions.

The truth seeker does not allow the unsupported claims of nostrum-venders, political spellbinders, and high-pressure salesmanship, or the propaganda of warring labor factions, political parties, or nations to determine his judgments.

He withholds his judgment until he has exhausted his resources of evidence. He reaches conclusions, but he does not jump at them.

7. He Is Able to Recognize Fellow Truth Seekers. It is hopeless to attempt to repeat and verify all the scientific work of past ages, and it therefore becomes necessary to depend upon the work of others for most of one's information. But authorities are judged by the evidence they give for their conclusions rather than by their wealth or whiskers.

8. He Is Undaunted in His Pursuit of Truth. It takes a great deal of painstaking effort, patience, and perseverance even to begin to discover the facts necessary to solve a problem adequately. The truth seeker keeps trying even after many failures. Work for him is a pleasure because it leads to one of life's greatest satisfactions, that of solving problems. He who believes that "a person is foolish to work" will never enjoy the fruit of the tree of knowledge. The scientist really enjoys life; the only drudgeries for him are the tasks that take him away from his pursuit of truth. The day is never long enough, and life is all too short for the man who has the passion for truth.

9. He Does Not Subscribe to the Adage, "What You Don't Know Won't Hurt You." He has learned from experience that there is nothing more terrible than ignorance in action. He knows that knowledge provides the power to prevent and cure disease, to prolong life, and to control his environment. He has learned that it is what he does *not* know that hurts him, for nearly always "forewarned means forearmed."

10. He Cultivates Accuracy of Observation and Precision of Statement. The truth seeker knows that no detail is too small to be of importance. Many of the great discoveries of Science have resulted from very small variations in measurements.

Deliberate dishonesty, distortion of truth, the selection of facts which support a preconceived point of view, inaccurate measurements, and careless statements are obstacles blocking the pathway to truth.

The truth seeker welcomes criticism of his work because it helps him to correct his mistakes.

11. He Is Optimistic. The scientist never says that a thing cannot be done but rather says "give me a chance at it." The fact that a thing never has been done before presents a challenge rather than discouragement.

12. He Is Brave. True Science, like art, is the outcome of a personal, creative ordeal.

The truth seeker fights all sham, deception, and falsehood which stifle progress. The priceless ingredients of every achievement of Science are the faithfulness and vigilant mental integrity in the use of facts and conclusions and the courage of those who made possible the achievement.

The Scientific Attitude Requires Conscious Effort for Its Cultivation.

The above attributes of the scientific attitude represent goals toward which one should strive. No one is born with the scientific attitude. Those who have acquired it have done so by conscious effort. No scientist possesses all of these attributes to a degree that one could point to him as an ideal example after which to pattern.

The spirit of the scientific attitude, as of other attitudes, is caught perhaps more than it is taught. The spirit or the ideal may often be caught from one's association with a person who has been unusually successful in developing it in his own life; thus, the association with a great teacher may be more valuable than any facts learned in college because of the inspiration received from him. Such an experience is not open to many students because teachers who apply the scientific attitude to all of the problems of daily life are so scarce. However, there is open to every student the opportunity to read the biographies or, better still, the writings of the world's greatest scientists, whose lives exemplify the attributes of the scientific attitude. In reading these biographies you will receive encouragement and renewed hope as you see the human frailties of even the greatest scientists. You can profit from their deficiencies and pattern after their strengths. In studying the lives of these men, whom you will come to love just because they are so human, you will see how successful the scientific attitude is as an approach to the solution of problems, even when it is very imperfectly developed.

You are strongly urged to read some of the biographies of great scientists listed in the Bibliography for this Unit at the end of the book. *The Life of Pasteur* by Vallery-Radot or *Madame Curie* by Eve Curie are especially recommended.

The scientific attitude grows with practice once its spirit has been caught. It requires deliberate, unrelenting effort to develop the scientific attitude. It is a lifelong battle, but the rewards make it worth while.

Begin today, starting with the small, more easily solved problems, to cultivate the characteristics of the scientific attitude. Some suggested

problems are given at the close of the next Section. They are not listed in this Section because the desire to seek truth is not enough. You must also learn the method which experience has shown to be so successful. This method, the scientific method, is outlined in the next Section.

Many people who have not cultivated the spirit of Science have learned the method. One may recognize such people by the fact that, while they are quite successful in solving problems in a restricted field in which they have specialized, they do not apply the scientific method to all of the problems of life. These specialists are not the great creative workers but rather the hod carriers of Science. Science needs many workers who have mastered the technique of obtaining knowledge. The method works where it is tried, but when it is not applied to all of the problems of life it is because the spirit is lacking. For the hod carriers, in whom the scientific attitude is lacking, the scientific method is a mere bread-and-butter type of thing in which work is done along well-established lines with care being taken not to be considered unorthodox. For the true scientist, on the other hand, the scientific method is the key to a glorious lifetime of adventure in the quest of truth.

Everyone Should Seek Truth.

We distrust leaders who disregard the truth. We lose faith in teachers who are dishonest. We avoid businessmen who misrepresent their merchandise. We expect our auto mechanics to make only those repairs that are needed on our cars. We do not want our physicians to base their treatments on guesswork. We respect the "weather man" because his conclusions are based on objective evidence.

But sometimes we forget that the scientific attitude is needed in the selection of a course of study, a school, a suit of clothes, a vocation, or even a life-mate.

If you are sick, you need to be scientific in selecting your physician. When you eat, you should select your food in accordance with your bodily needs. If you build a house, you should select your lot, architect, contractor, and type of house scientifically. In general, there is no problem which cannot be solved best by the scientific approach.

The Search for Truth Is Essential to the Progress of Humanity.

The progress of humanity will be determined by the extent to which every individual is a truth-seeker.

In this age of high-pressure advertising, clever and cunning propaganda, complicated living, complex paradoxes, apparent contradictions,

and varying standards of conduct, even the most scientific person finds it difficult to make wise decisions. Success is a measure of one's correctness in solving problems.

STUDY QUESTIONS

1. Make a list of the various attitudes, such as indifference or selfishness, which influence men in voting, and consider the results.
2. *a*) Select from the following list those adjectives which describe the scientific attitude: open-minded, dogmatic, opinionated, humble, cocksure, narrow-minded, conceited, intolerant, prejudiced, skeptical, gullible, orderly, objective, subjective, imaginative, persevering, persistent, conservative, radical, constructive, truthful, accurate, dishonest, suspicious, patient, impatient, careless, impulsive, emotional, foresighted, indiscreet, discriminating, curious, haughty, confused, indifferent, lazy, industrious, cautious, methodical, orderly, efficient, creative, imitative, inquisitive, flighty, composed, superstitious, rational, modest.
   b) Which of these adjectives best describe you?
   c) Which of these adjectives would you like to have someone use in writing a recommendation for you?
3. Do you think that one should be scientific in selecting a mate? Granting that it is too late to use one's intelligence once he has "fallen in love," could one use his intelligence previous to that time so that he would be more likely to "fall in love" with the right person?
4. Which of the following common errors would be avoided by one who has the scientific attitude? Point out in each case which attribute of the scientific attitude would oppose the error.
   a) To expect others to conform to our standards of right and wrong.
   b) To measure the satisfactions of others by our own.
   c) To find perfection in our own actions.
   d) To expect perfection in the actions of others.
   e) To be indifferent to human suffering.
   f) Not to make allowances for the weaknesses of others.
   g) To consider anything impossible that is impossible to ourselves.
   h) To be swayed by mobs.
   i) To refuse to consider conclusions which do violence to our own beliefs.
5. Why do many people prefer fiction to truth, unreality to reality, acting to living, or impossible claims to facts?
6. How does the scientific attitude differ from other attitudes?
7. List the characteristics of a man possessing the scientific attitude.
8. Why does the scientist abstain from making statements that claim to be "the absolute truth"?
9. Compare the scientific attitude with other attitudes as to their effectiveness in leading to the goal of humanity.
10. What motivates you in the solution of your life problems?
11. What is your attitude toward "the printed page"?
12. What is your attitude toward modern advertising in radio broadcasts, newspapers, and magazines?
13. Analyze your attitude toward the use of tobacco.
14. Analyze your attitude toward "cheating."

15. Are there some aspects of human life in which the scientific attitude should be deliberately cast aside?
16. What should be the attitude of the scientist toward those phases of Science which he is not qualified to criticize?
17. Criticize the statement, "It is most frequently the ignorant mind which is in doubt, and the scientific mind which is ready with a positive answer."
18. Criticize the statement, "By expressing a confident opinion on almost any question which is placed before one, one thereby shows a strength of mind."
19. Criticize the statement, "It sounds plausible, what more can you ask?"
20. Criticize the statement, "Ignorance is bliss."
21. Is truth worth living for?
22. What values are so important that truth can be disregarded in trying to attain them?
23. What effect did the World War of 1914–1918 have upon the pursuit of truth and the scientific attitude?
24. Why are so many people fooled by certain sorts of propaganda?
25. How does a scientifically trained person react to a new situation or experience?

UNIT I

SECTION 3

THE SUPREME CONTRIBUTION OF SCIENCE TO HUMANITY IS ITS METHOD OF SOLVING PROBLEMS

The acquisition and systematizing of positive knowledge is the only human activity which is truly cumulative and progressive. — George Sarton.[1]

Introduction.

In this section you will study the method which Science has found to yield amazingly satisfactory results in solving problems. This section should be read and reread frequently during the year until you thoroughly understand the significance of every statement.

You should learn the scientific method by using it in solving some of the problems listed on pp. 25 and 26 or in solving problems of your own.

The steps in the scientific method do not necessarily follow the order outlined, and all of the steps may be repeated over and over again in solving a single problem because problems give birth to new problems and each problem turns out to be composed of many smaller problems. The important thing about the scientific method is that generalizations are based on and tested by data rather than desire, prejudice, plausibility, or any other consideration.

The First Step in the Scientific Method Is the Location and Definition of a Problem.

It is seldom difficult to recognize a felt need, but experience has shown that in case we cannot think of a problem that has not already been solved, all we have to do is to start gathering data and a problem will soon present itself.

The problem should be carefully defined in words that are clear and all irrelevancies should be eliminated. In defining the majority of problems, data must be obtained.

[1] *Introduction to the History of Science*, Vol. I, Williams and Wilkins, Baltimore, 1927.

The Second Step in the Scientific Method Is the Formulation of a Possible Solution of the Problem.

There are two approaches to the formulation of *possible solutions to problems*, which are called *hypotheses*. One approach, called the *inductive method*, starts with data obtained by observation and then uses these data as the basis for the hypothesis.

In another approach, called the *deductive method*, one starts with the hypothesis, *i.e.*, a broad assumption the validity of which is generally accepted, and then obtains data to check the assumptions on which the hypothesis was based. Thus, the deductive method is the exact opposite of the inductive method.

Do not concern yourself too much about induction and deduction; both methods are equally valid. The important thing is not which comes first but rather the fact that both can be subjected to the same tests and checks. Most of the great generalizations of Science are a result of the application of the inductive method, but the deductive method is often the simpler one, especially when one is dealing with familiar situations. The inductive method proceeds from a host of facts to broad generalizations. The deductive method, on the other hand, starts with a broad generalization and adapts it to new situations and new sets of facts.

The Third Step in the Scientific Method Is That of Testing and Verifying Conclusions.

One of the elements of the success of Science in solving problems is that it does not accept its own conclusions, no matter how reliable or extensive the data on which they are based, nor how plausible the conclusions are, nor even how well they fit into previous ideas. In Science a conclusion is tentative; it is something to be tested. Such tests involve the collection of additional data. New generalizations are thus obtained, and so the process continues, constantly gaining momentum.

A generalization is tested by figuring out what ought to happen if the generalization is true and then observing whether or not these predictions are verified by experience. Even if the generalization is verified, it may not be regarded as a law until it has been shown that all other possible generalizations will not stand the test of experience.

Data Are the Result of Bare Observations and Experimental Observations.

Careful records of observations are called data. Data are obtained by (1) bare observation, *i.e.*, observation made under uncontrolled con-

ditions, and (2) experimental observations, *i.e.*, observations made under controlled conditions.

While a science may be and usually is born out of bare observation, experience has shown that it develops best when such observational data are supplemented by experimental data. The possibilities of bare observation have not been exhausted. Experiments are devised because our powers of observation are generally so dull or our experiences are so limited.

Both types of observations must be capable of being repeated by others. Accuracy, impartiality, and honesty are thus required of truth seekers.

Generalizations Differ in Reliability.

Data are collected, sorted, arranged, and classified, with the result that certain regularities or things-in-common become evident.

On the basis of such relationships we arrive at a generalization or "regularity of nature," *i.e.*, a general statement concerning the behavior common to a large number of cases. Such generalizations simply state what we expect will happen under given conditions because it always has happened under those conditions. When new conditions are discovered, the law is revised to include them.

No human mind is perfect, and for that reason no generalization can be considered to be correct even when it is based on well-verified data. All scientific generalizations are subjected to careful scrutiny by many workers, and the majority of these generalizations have been found to be untrue under certain circumstances, *i.e.*, only partially true. Others, which stand the test of time and experience, are accepted as correct and are called laws. Most of our scientific laws have been revised repeatedly as additional information showed that they were inaccurate or inadequate.

Scientific Laws Differ from Civil Laws.

Civil laws may be changed or repealed out of existence. If one does not choose to be guided by civil laws, it may be possible to violate them without paying any penalty. In fact, it is difficult to live today in the United States without violating many laws on the statute books. Civil laws require the backing of public opinion and enforcement machinery to make them effective. "The civil law involves a command and duty; the scientific law, a description, not a prescription." [1]

Sometimes a scientific law appears to be violated. For example, when water runs up a tree, it seems contrary to the law of gravity. But

[1] Karl Pearson, *The Grammar of Science*, Charles Scribner's Sons, New York, 2d ed., p. 87.

the gravitational attraction of the earth for the water is the same as usual; there is a greater upward force of attraction due to capillarity and other factors. One force transcends another force, but there is here no exception to any law.

Scientific Laws Are Frequently Revised.

The value of a generalization is that it enables the scientist to predict what will happen under given conditions. The scientist is naturally interested in checking his prediction, for such a check serves as a verification of the reliability of his original observations. Testing predictions leads to limitations of the law as it is found to hold true under certain conditions but not under other conditions. Few, if any, laws as stated by man are exact, *i.e.*, few laws hold true under all conditions.

Theories Are Integrating Explanations.

A theory may be likened to a view from an airplane in that it enables one to see many things in their proper perspectives and relationships. A theory knits together large bodies of data and laws. A hypothesis is an explanation which is not adequately substantiated, while a theory is a tested and accepted hypothesis. Theories constitute the most useful portion of *organized* knowledge, which truly is Science.

Theories Have Three Useful Functions in Science.

1. ***Theories Suggest New Generalizations.*** *A theory is a series of assumptions* which enables one to deduce one set of generalizations from another apparently unrelated set of generalizations, thus giving guidance to the truth seeker as he pushes forth into the unknown.

The great value of a theory is not the correctness of its assumptions but rather the fact that it does lead to new generalizations without the necessity of gathering a great deal of data.

2. ***Theories Often Enable Us to Bridge the Gap between Qualitative and Quantitative Generalizations, Thus Combining the Values of Each.*** Logic, which is an integral part of all theories, is of two kinds, qualitative and quantitative. Quantitative, *i.e.*, mathematical logic, is needed in handling quantitative data. The statement that "you can prove anything by statistics" shows how common it is to use qualitative logic when dealing with quantitative data. Quantitative logic when used in qualitative thinking produces pathetic errors. Neither type of logic is superior to the other. Each must be used in its place. Both of these types of logic will be discussed in Section 6 of this unit.

Preconceptions, "hunches," sometimes called "revelations," frequently suggest themselves before the data at hand could possibly be adequate to justify such generalizations. Such flashes of genius are

great time-savers. Generalizations have to be tested in every case, and if a generalization can be obtained without the very laborious accumulation of data, it is all the better. Such working hypotheses are not "unscientific." They seem to come to the greatest, *i.e.*, the most creative, scientists more often than to others, and it appears that they are the result of unconscious processes which can be consciously stimulated and depend, in part at least, upon observations made but not consciously recorded.

3. Theories Link Together Apparently Unrelated Generalizations, Thus Unifying All Branches of Knowledge. Today there is a greater need for comprehensive theories than for more data. Such theories can be derived only by those people who have comprehensive knowledge. Thus specialization, so essential in controlled observation, or experiment, is the wrong type of training for creative thinking of the type that is needed.

Theories bring together the data obtained by specialization. Scientists must be trained in both observation and generalization, or, if this is not feasible, provision must be made to train *generalizers*. We are now doing a good job of training data-gatherers, the so-called hod carriers of Science.

Science Is Limited by the Ability to Obtain Data.

The mind is capable of producing generalizations concerning ultimate values, the nature of God, immortality, etc., which Science has no method of testing today. Science is thus not in a position to determine whether these generalizations are true or not. The fact that millions of people in isolated portions of the earth throughout thousands of years have independently arrived at generalizations, such as the existence of God, is the strongest and perhaps the only argument in their favor, but *until* Science can obtain data to check such generalizations, they must remain as problems outside the realm of Science. This statement does not mean that there are any sacred problems which Science dare not approach or which, by their nature, must forever remain outside the province of Science. It simply means that many of man's most important generalizations have to be accepted on faith until great walls of ignorance can be pushed back.

The Ability to Solve Problems Is Learned by Solving Problems.

> How to think fruitfully, logically, scientifically . . . should be a major tool in the educational equipment of everyone. . . . But such technique is not taught in isolation in the confines of the classroom, as is almost universally the case . . . but in close touch with practical, concrete situations developed in the life of the community. . . . — H. E. Cunningham.

There is no royal road to learning. One learns by effort, becomes a scholar by study, acquires accuracy by being accurate, gains experience by enduring experience, and becomes observant by constantly observing. As one thinks and does, so he becomes.

Problem-solving, like other skills, is learned by doing. It must be kept in mind, however, that learning is most fruitful when it is meaningful. The kinds of problems solved will determine how much you learn about problem-solving. If you select problems which are associated with a felt need or a conscious goal, they will result in learning because they are meaningful. Experience has shown that one does not develop the technique of solving problems by applying it to laboratory experiments unless these experiments represent solutions to felt needs.

One of the most important activities in which you can engage this year is to learn to solve problems by solving a few real problems.

Problems range from very simple ones, whose solution requires very little intelligence, to those which have baffled our greatest geniuses. Your greatest satisfactions will come if you select immediate problems which are not too complex for your first few attempts. More difficult problems may be selected as your skill in solving problems increases. The following suggested problems may help you to discover a real problem for yourself.

1. Selection of a vocation
2. Selection of friends
3. What courses shall I take?
4. Shall I plan to complete a college course?
5. How can I earn better grades?
6. How can I develop social skills?
7. How can I obtain a "good buy" in purchasing a used car?
8. Which oil or gasoline for my car will be the "best buy"?
9. How am I to know which cosmetics are harmless or harmful?
10. How can I be sure that my teeth will not give me trouble in later life?
11. What kind of razor shall I use?
12. Do I eat the foods necessary to maintain resistance to disease?
13. What are my strong points?
14. What habits am I forming?
15. Shall I smoke?
16. Shall I dance?
17. Shall I enter into church activities?
18. What movies shall I attend?
19. What school activities shall I engage in?
20. How shall I select my "dates"?
21. Shall I engage in "petting"?
22. How can I be most useful at home?
23. How shall I select a physician?

24. How shall I select an auto mechanic?
25. How shall I buy insurance?
26. How may I learn to vote intelligently?
27. What shall I do with my vacation time?
28. How shall I keep out of debt?
29. How shall I select a dentist?
30. How shall I select a lawyer?
31. How shall I select a new car?
32. What soap, dentifrice, shaving cream, or cosmetics shall I buy?

STUDY QUESTIONS

1. What are the two types of observations? Would it be correct to say that either type is unscientific?
2. Why are scientists often accused of being absent-minded?
3. What are the three contributions of a theory to the scientific method?
4. Why is it better to say that generalizations are based on "data" rather than "facts"?
5. Criticize the statement, "Scientific laws are unreliable because they are subject to revision."
6. What are the different steps in the scientific method?
7. Does it make any difference whether you "believe" in a theory or not? Use the theory of evolution as an example.
8. How does the scientific pursuit of knowledge differ from the pursuit of knowledge as commonly illustrated in law courts? How is it the same?
9. What determines the usefulness of scientific theories?
10. Does every scientist test all of the conclusions in his field?
11. Criticize the statement, "A hypothesis becomes a scientific theory when the majority of the people agree with it."
12. How does the scientist treat evidence which disagrees with accepted theories?
13. Do scientific hypotheses ever conflict with each other?
14. The first step in choosing a vocation, as in all other problems, is the location and definition of the problem. How would you change the following attempt to define this problem as worked out by a student?
    (1) The vocation must fit in with my ideals, *i.e.*, what I expect to get out of life.
    (2) It must be something that I can learn to do well.
    (3) It must be selected from several possible alternatives on the basis of the opportunities afforded and the needs of humanity which it satisfies.
    (4) It must require my best efforts and stimulate continuous growth.
    (5) It must be something that I like.
15. Why should a teacher be scientific?
16. In what respects can the housewife use the scientific method?
17. Why should the scientific attitude and method be learned early in life?
18. What problems does a student have which can best be approached scientifically?
19. Why should a physician use the scientific method?
20. Would the scientific attitude and method be of any value to an artist, a musician, or a poet?

21. What problems are involved in building and furnishing a new home? In what respects would the scientific method be of value in solving these problems?
22. A student in a typical college in the United States interviewed twenty-one of his classmates selected at random, asking:

    (1) What is the scientific method?
    (2) Have you studied any Science courses?
    (3) Do you apply the scientific method to the problems of daily living?

Out of twelve who "had heard of the scientific method," only two could see how it could be applied to daily living. The other ten students did not know what the scientific method was. Two thirds of these twenty-one students were then taking "Science" courses. One student who was doing premedical work stated that the scientific method had no particular significance to him outside of scientific and laboratory studies! Discuss the above data. If you are interested, try making a similar survey of some of your classmates.

UNIT I

SECTION 4

OBSERVATIONS MUST BE CONTROLLED AND CHECKED TO INSURE THEIR RELIABILITY

Introduction.

Man is excelled in each of his senses by some other animals, but he is distinguished from these animals by his intelligence, which enables him not only to plan and control his observations but also to devise instruments to aid or supplement his senses. The habit of getting along without the use of the senses, in so far as possible, leads not only to less interesting living but also to less intelligent living because observations are necessary for the testing of generalizations.

It is the purpose of this section to show how observations in the realm of physical science are aided, controlled, and checked to insure their reliability.

At Best, Man's Senses Are Very Limited.

A brief survey of some of man's best known senses will be sufficient to show how limited is the range of his sensory faculties.

1. Vision. There are many kinds of motions that are too quick or too slow for the unaided eye to detect them. The eyes cannot shift from one image to another more often than ten times a second, so that projection of sixteen separate pictures per second leads to the illusion of the continuous, smooth, steady motion of the movies.

The range of vision is also greatly limited as to the size of particles that are visible and as to the distance at which they are visible.

The normal human eye cannot see separately the components of any color but receives all of the wave lengths of the visible spectrum as one sensation. Thus white light is seen to be white rather than a mixture of all the colors of the rainbow.

2. Hearing. The human ear is sensitive to sound waves having frequencies between 30 and 30,000 per second. Vibrations below and above these frequencies are very difficult to detect. The ear can recognize only a limited number of simultaneous sounds.

3. Taste and Smell. Taste and smell are chemical senses, limited in range and not subject to mechanical aids as yet. These senses are said to be chemical because they can detect the presence of molecules of many different kinds of substances. Man can distinguish between only the four tastes of sweetness, sourness, saltiness, and bitterness. Flavors, like perfumes and all other odors, are smelled rather than tasted, as anyone with a congested nose can prove.

These chemical senses are remarkably sensitive. For example, one part of vanilla can be detected in 10,000,000 parts of air. The sense of smell can be trained to the extent of making possible the identification of hundreds of different substances, but very few people can identify even a fraction of this number.

4. Skin Sensibility. Man's skin sense organs can distinguish between heat and cold only relatively and can measure heat only roughly. The sense of touch is again not capable of making exact observations.

5. Deep Sensibility. Deep sensibility includes several senses such as muscular, tendon, and joint sensibility as well as static and equilibratory senses. People differ greatly in their ability to estimate direction, distance, weight, and pressure, or to maintain their balance.

The Senses Differ Widely among Individuals.

The differences in individual sensitivity vary from complete loss of function to slight abnormal variations such as color blindness or hearing which is not sensitive to certain ranges of vibrations. Certain odors which smell "bad" to some individuals will smell "good" to others.

The Senses Often Yield False or Misleading Information.

The eyes are man's most useful sense organs, and yet they cannot be trusted. For example, William H. George (*The Scientist in Action*, Emerson Books, Inc., 1938) relates an experiment in which forty people at a masked ball were asked to write a report of a carefully planned act in which a clown was chased into the hall by a negro carrying a revolver. After a scuffle the negro fired a revolver, and both rushed from the hall, the whole action lasting about twenty seconds. Only one of the forty reports had fewer than twenty mistakes, whereas twenty-four accounts contained at least 10 per cent of details which were pure inventions.

The other senses also yield false impressions under certain conditions; for example, a room which feels warm to one coming in from the outside where it is very cold may feel cold to someone else who enters the room from a still warmer room.

Instruments yield more reproducible results than man's unaided

senses, in part, at least, because they make it possible to isolate observations.

The Reduction of Errors in Observation Is One of the Major Problems in the Search for Truth.

1. The Senses May Be Made More Reliable through Training. James G. Taylor (*Popular Psychological Fallacies*, Watts and Company, London, 1938) points out that the minimum distance on the back of the shoulder at which one can discriminate between two points is nearly two and one-half inches. After a week of practice, however, one can feel two points at less than one inch apart when placed on either shoulder, although only one shoulder has been used in practice. It appears that practice is just as important as the number of sense organs in the skin.

Through training, one may learn how to identify wines by tasting them, to test teas by sipping them, to test the freshness of eggs by smelling them, to tune instruments by ear, to match colors by comparison, or to tell when a batch of steel is ready to be poured by looking at it.

One of the most important objectives of laboratory work in the physical sciences is to develop techniques, *i.e.*, the ability to make accurate observations with different types of instruments.

It is important to remember, however, that practice never makes perfect and that even the most experienced observers may make mistakes because the human organism is continually changing.

2. Alertness May Be Increased by Conscious Effort. Scientific observation is not an aimless gazing at things. It is genuine work because it requires nervous energy to be alert not only to the things for which one is looking or in which one is interested but also to things in which one is not interested.

Few people even *attempt* to see what there is present to see *because their interests are restricted.* The reason specialists often arrive at erroneous conclusions is because their interests cause them to select the observations which they make.

Some people notice the colors or types of clothing displayed in show windows, whereas other people will notice the lighting arrangements or the type of construction of the building. Still others may be so absorbed in their thoughts that they will walk right into the window. No wonder that a group of people cannot agree in their description of an accident which every member of the group has witnessed.

In spite of the determination to do so, no one can be alert to everything that goes on around him, and every man will be influenced by his

interests in making observations. How can these errors due to the human equation be eliminated?

3. Instruments Must Be Calibrated. Calibration consists of comparing instruments with standards and adjusting the instruments so that they will give the same results as other similarly calibrated instruments. Cheap thermometers, for example, may give temperature determinations which vary several degrees among themselves, but every thermometer which has been carefully calibrated will give the same temperature reading under similar conditions.

It is never safe to assume that an instrument will yield reliable results. Perhaps the person who last used a calibrated weight touched it with an oily hand, thus changing its weight. The careful observer frequently checks and rechecks his instruments to be sure that they are yielding reliable data.

It is quite possible that every instrument of a given type will yield inaccurate data because of errors or limitations which are inherent in the instruments themselves. How may such errors be eliminated?

4. Checking Is the Most Successful Method of Eliminating Errors in Observation. Repetition of observations by any one observer enables him to detect errors which may have entered into one observation but not another.

Repetition of observations using different instruments of a given type serves to eliminate errors due to faulty calibration.

Repetition of observations using instruments of entirely different types serves to eliminate errors inherent in any given type of instrument.

Repetition of observations by different observers serves to eliminate errors due to the prejudices or to the differences in the sensitivity or alertness of the observers.

Mistakes are avoided in scientific laboratories, banks, stores, hospitals, or at home by checking and rechecking. No information should be accepted as being reliable until it has been checked.

Gullibility is inaccuracy, and even costly mistakes are the common results of the failure to check observations in all of the phases of daily living.

Experimentation Is Observation under Controlled Conditions.

Many phenomena are so complex that they can be studied only by observing the changes resulting from altering one factor at a time while other factors are kept constant.

Perhaps the most significant feature of controlled observation is that it enables many different observers to study exactly the same situations and to check, correct, or supplement each other's results.

Observation Involves Both Analysis and Synthesis.

One has not really observed a building until he has taken it apart (analysis) so that he can see and measure each individual part. On the other hand, one has not really seen a building until it is constructed, even though he may have seen each individual part and has studied the architectural drawings. A watch cannot be observed adequately when taken apart; it must be running in order to permit the most meaningful observations. Putting things together is what is meant by synthesis.

Thus analysis breaks things down so that each part can be observed, whereas synthesis puts things together so that the behavior of combinations of things can be observed. As a rule analysis precedes synthesis.

New Instruments Make New Observations Possible.

The invention of new instruments is one of the most important contributions to the advancement of knowledge. Thousands of instruments have been invented to enable man to make more exact and more accurate observations: for example, the modern automobile mechanic uses gas analyzers to enable him to make better carburetor adjustments; the criminologist uses polygraphs to detect lies; physicists use cyclotrons to study changes in the nuclei of atoms; and the modern electron microscope extends the range of the study of micro-organisms still further.

Measurement Is the Master Art.

In obtaining data, the scientist must describe objects or phenomena as accurately as possible; and in nearly every case, such a description involves quantitative measurements, which must be expressed mathematically.

Measurements of high precision are prerequisite to the mass production of modern machines with their interchangeable parts. Measurement is not only essential to the best architecture, sculpture, painting, or music, but it is the foundation of the exact knowledge which is known as Science.

The modern theory of measurement is based on the assumption that nearly all physical phenomena may be measured in terms of length, mass, and time.[1]

Units of measurement, *i.e.*, standards for comparison, are of great importance. It would be interesting to study the gradual evolution of such units as the fathom, the pace, the cubit, the foot, the span, the acre, the bushel, the quart, the gallon, the pound, and the ton. Everyone who has spent so much of his time in school learning the units in

[1] The units of time are discussed in Unit 2, Section 9.

the English system of measurement, which date back to the time of Edward I (1324), should do his part to hasten the time when the modern simple metric system is universally adopted. Modern Science has made possible the development of communication and transportation throughout the world to such an extent that the progress of civilization will be seriously impeded unless a uniform system of units of measures and exchange is adopted.

In 1790 the French National Assembly appointed a committee to set up a permanent standard of weights and measures. This committee selected as the unit of length approximately one ten-millionth of the distance from the North Pole to the equator. This unit, the meter, is now taken as the distance between two marks on a platinum-iridium bar (at 0° centigrade) kept in the archives of the International Metric Commission at Paris, and of which duplicates are possessed by most of the leading nations of the world.

The Metric System Is the Decimal System Applied to All Types of Measurements.

Mass. Gram (mass of a cubic centimeter of pure water at 4° C.)
Kilogram (1000 grams)
Milligram (0.001 gram)

Length. Meter (length of a standard prototype in Paris at 0° C.) It was intended to be one ten-millionth of the mean distance from the equator to the North Pole.
Centimeter (0.01 meter)
Millimeter (0.001 meter)
Micron (0.000,001 meter)
Millimicron (0.000,000,001 meter)
Angstrom (0.000,000,000,1 meter)
Micromicron (0.000,000,000,001 meter)
Kilometer (1000 meters)

Volume. Liter (volume of a kilogram of water at its maximum density, 3.98° C.)
Milliliter (0.001 liter)

The Educated Person Knows Where to Obtain the Data That He Needs to Solve His Problems.

Inasmuch as the majority of observations require specialized training and instruments to obtain them, it is not possible for any one to observe for himself all of the data that he requires for the solution of his problems. One of the marks of an educated man is that he knows not only what kind of information is needed and where it can be located but

that he also possesses the critical faculty which enables him to distinguish between fact and fiction.

STUDY QUESTIONS

1. Can you think of examples in which the senses give incorrect impressions because of previous associations? For example, a cup of coffee containing a lump of dry ice will appear to be steaming, and the observer reports that the coffee is steaming-hot. How may such errors in observation be eliminated?
2. Can you add to the following list of possible sources of information concerning a physician? Which of these sources of information would you have selected before reading this list? Which of these sources would you consider to be most reliable? What type of information would you expect to obtain from each source? Which sources would you try at first, and which ones would you use as checks?

   Police records, druggists, medical schools and undergraduate colleges, churches, neighbors, hospital where interne work was done, medical associations, hospitals where the physician sends patients, better-business bureau, credit-rating bureau, dentists, clinical and X-ray laboratories, specialists in allied fields, oculists, undertakers, insurance agents, health centers, emergency hospitals, lodges, physicians in neighboring cities, chamber of commerce.
3. List the most important senses and point out briefly how each sense may contribute to untrue or inadequate observations.
4. List some of the particular examples of abnormalities in the sense organs which you have observed to yield inaccurate data.
5. What do you consider to be the greatest source of error in making observations?
6. How may errors in observation be avoided?
7. How does experimentation differ from casual observation?
8. How do scientists and nonscientists differ in regard to the observations that they make?
9. What objectives of laboratory training were mentioned in this section?
10. What objectives of general education were mentioned in this section?
11. Define the fundamental units of the metric system of measurement.
12. Why should the metric system of measurement be universally adopted?

UNIT I

SECTION 5

ORGANIZATION IS NECESSARY TO GIVE SIGNIFICANCE TO DATA

Introduction.

While mathematics has often provided tools far beyond the needs of the Science of the time, on the other hand, many data have not been capable of interpretation until many years after they were obtained because the mathematical tools had not yet been invented.

A great deal of the time required for the preparation for work in the physical sciences must be devoted to the mastery of such tools as algebra, plane geometry, descriptive geometry, solid geometry, trigonometry, and differential and integral calculus. This training in the use of the mathematical tools of Science is just as important to the elimination of errors in organizing, classifying, and interpreting data as is training in the use of the senses in obtaining reliable data.

There Is No Ultimate Form of Mathematical Reasoning.

Mathematics provides methods of arriving at general conclusions based upon certain arbitrarily chosen definitions. It is very important that these definitions be so clearly and concisely stated that every scientist will use the same definition. The chief reason for the multiplicity of technical terms in Science is that they are necessary to provide precise definitions. If new postulates are introduced or old terms are redefined, the mathematical treatment has to be revised accordingly. Thus Newton's assumption that time and space are independent gave rise to a system of mathematics differing considerably from that based on Einstein's postulate that time and space are related. There is no ultimate form of mathematical reasoning any more than there is any ultimate form for an automobile or airplane. The forms in each case change as old faults are eradicated and new improvements are added. Inasmuch as all scientific generalizations are obtained by mathematical reasoning based on arbitrarily chosen assumptions, it is quite evident that there is no absolute generalization in Science and that any tentative generalization or even law is subject to change when new data indicate that certain original assumptions were not justified.

A knowledge of mathematics is essential in interpreting many data, but a knowledge of statistics is of equal importance because statistics enable one to determine what data to use.

The Essential Feature of Statistics Is the Judicious Disregarding of Details.

Every measurement involves some error and, for that reason, it is extremely important that the amount and significance of these errors always be taken into consideration. This latter problem is the business of statistics.

In many cases it is impossible to measure individual members of a class. Thus the chemist determines the behavior of a large number of atoms rather than that of a single atom. Statistics is a procedure for measuring groups rather than individuals.

When comparing two groups in experiments using one group as a control and varying the factor being studied in the other group, differences in the data will be observed. Are these differences the result of pure chance, or have they some experimental significance? This is the kind of problem that statistics answers.

In case one desires to combine several observations of different degrees of accuracy, statistics shows that each item should be weighed inversely as the square of the probable error of the observation, and it is the business of statistics to show one how to calculate the probable error of the determination.

The normal probability curve is brought into use to tell when doubtful observations are to be rejected. See p. 236 for a normal probability curve. Some recent developments have indicated that many of the laws of nature are laws of chance, *i.e.*, they are statistical. They are based on the theory of probability; life insurance depends upon this theory for its very existence. No insurance company can predict when any individual will die, but it can calculate with remarkable precision how many deaths among persons of a given age will occur during a year in a country at large.

Certain aspects of the kinetic theory of gases are based upon probability. See Unit IV, Section 5.

One of the most important problems involved in analyzing experimental data is to locate the mathematical equation which will best express the results. This is again a problem for statistics to solve.

Space will not permit a detailed treatment of statistics here, but everyone should know that the interpretation of data may require statistics. A good statistician would not make the error of averaging the height of all trucks in order to determine the clearance to allow

in a highway tunnel. Neither would a statistician average the two numbers 12.56 and 5 to obtain the result 8.78, because the number 5 has no significance in so far as the decimal places are concerned.

In analyzing the grades made in a course, there are several statistical terms which are just as important as the arithmetic average, such as median, mode, and measure of dispersion.

Suppose that you have the weights of ten thousand people of your own height, age, and sex, selected at random. Would this figure represent the average weight of all of the people of your country of the same height, age, and sex? The answer to this question depends upon how the sampling was done and whether or not the sample of ten thousand people is large enough. Suppose that it is not large enough, then how large a sample should you have? That information is for the statisticians to determine.

In treating the data from ten thousand such cases, the ordinary person would simply determine the ordinary arithmetic average, but the statistician would not stop at this point. He would then compute the standard deviation, that is, how the weights are dispersed, or, in other words, the extent to which the weights are scattered above and below the average. He also determines the mode, that is, the weight which occurs most often among all of the weights.

Suppose that you know the standard deviation and the mode; of what value is this information to you? Probably none. But such measures are important to the statistician in the determination of the probable error. In considering statistics, always look for an accompanying statement concerning the probable error, because statistical data may have such high probable errors that they may represent downright lies (which the scientist would call "nonsense").

The usual method of rounding off numbers in all cases to the next highest is wrong because on the average it will lead to cumulative errors. The statistician has shown that the correct method is to round to the even figure. For example, 3.275 is rounded to 3.28, while 3.265 is rounded to 3.26.

Knowledge Has Been Classified into Specialized Divisions Called "Sciences" to Simplify Study and to Aid Research.

Knowledge becomes significant when it is organized. Because of man's inability to comprehend present knowledge *in toto* and in order to save time and effort, he has classified knowledge into a number of arbitrary categories. These subdivisions are called sciences. "It is because we do not possess 'Science' that we have 'sciences.'"

The main divisions of Science are defined and classified roughly as

follows. The definitions follow the usage given in the *Encyclopedia Britannica* in most cases.

I. *The Physical Sciences*

1. Astronomy — the science of the universe outside of our own planet
2. Physics — the science of matter and energy
3. Chemistry — the science of the composition of matter
4. Mineralogy — the science of minerals
5. Geology — the study of the structure of the earth
6. Geography — the study of the earth's surface and economic products, and their relation to living creatures, especially man
7. Meteorology — the study of climate and weather

Physics and chemistry are the fundamental physical sciences. The other physical sciences are special composite applications of these two fundamental sciences.

II. *The Biological Sciences*

1. Botany — that portion of the science of biology which relates to plants
2. Zoology — that portion of the science of biology which relates to animals
3. Paleontology — the science of extinct forms of life
4. Bacteriology — that portion of the science of biology which relates to bacteria
5. Physiology — the science of the functions of living organisms
6. Hygiene — the science of preserving health

III. *The Psychological and Social Sciences*

1. Psychology — the science of the mind
2. Language — the science of verbal communication
3. History — the science of past events
4. Anthropology — the science of the natural history of man
5. Ethnology — the science of man as a racial unity
6. Archaeology — the science of antiquities
7. Political Economy (Economics) — the science of wealth and mediums of exchange
8. Sociology — the science of human society
9. Education — the science of deliberate direction and training
10. Theology — the science of religion
11. Naturalistic Philosophy — the science of explaining all natural phenomena

The order in which these sciences are listed represents fairly closely the order of their historical development and to a certain extent the order in which they are studied, as would be expected.

Arithmetic, mathematics, logic, and metaphysics are sometimes

classified as sciences, but they are chiefly concerned with the method by which knowledge is obtained and expressed rather than with its content and are therefore not included in the above classification.

Literally hundreds of sciences could be added to the above list as subtitles under the above more inclusive titles.

The Sciences Are Closely Related.

The distinctions between these different sciences break down as knowledge increases, and it is through this coalescing process that some of the most far-reaching generalizations come.

The discoveries concerning the electrical nature of matter and the structure of the atom have made chemistry and physics almost one science. So closely related are the sciences that a general knowledge of most of the sciences becomes necessary for specialization in one science. In the study of the biological sciences, a thorough grounding in the physical sciences is necessary, while so many factors must be taken into consideration in the study of the social sciences that it is only within the last few years that enough has been known concerning some of them even to call them sciences.

No one can be an expert in many sciences, but through survey courses he may become at least familiar with the greatest generalizations in each field to know which experts to call upon for help when need arises. A lack of such general knowledge is illustrated by the type of ignorance that calls in a preacher when a physician is needed or that calls in a lawyer when a preacher is needed.

The Physical Sciences Are Integrated in This Text to Make Their Study More Meaningful.

In this book, which is devoted to the study of the physical sciences, an attempt has been made to integrate the fundamentals of each of the physical sciences in such a way as to give them the most meaning to the beginning student. For that reason, the study of each of the physical sciences has not been taken up in separate units. It is desirable, however, that you be able to recognize which of the physical sciences has been drawn upon to furnish the principal information for each section, because you may later want to take specialized courses in one of the fields of physical science in which you may become interested during the study of this survey of all of the fields of physical science.

Physics. Physics is the basic physical science because it provides the techniques of observation and the language for expressing the observations concerning inanimate matter and the changes which it undergoes. Physics is usually subdivided into the study of mechanics,

heat, sound, light, and electricity. Mechanical, civil, and electrical engineering are branches of applied physics.

Chemistry. Chemistry is concerned with the study of changes in the composition of matter, whereas physics is restricted to the study of those changes in matter which do not involve a change in the composition of matter. Chemistry is subdivided into inorganic and organic chemistry. Each branch of chemistry usually involves, first, a general survey of the whole field, followed by qualitative analysis and quantitative analysis. Physical chemistry is an advanced study in which physics and chemistry are so integrated that their identity is lost. The artificial barriers between physics and chemistry disappear for advanced workers in either field. For example, some of the greatest developments in the field of theoretical chemistry, such as the nuclear transformations of atoms, have been developed by scientists who call themselves *physicists.*

There are literally hundreds of branches of applied chemistry, among which may be mentioned rubber, fertilizers, soil, nutrition, leather, ceramics, metallurgy, plastics, explosives, water, and sewage.

Geology. Geology employs the fundamentals of physics and chemistry in the study of the form, structure, and changes of the earth.

Some of the more important subdivisions of geology are petrology, the study of rocks; volcanology, the study of vulcanism; and seismology, the study of earthquakes. The chief practical application of geology is petroleum geology.

Mineralogy. Mineralogy applies the principles of chemistry and physics to the study of minerals. An important branch of mineralogy is crystallography, the study of the crystalline forms of minerals.

Astronomy. Astronomy deals with the study of the stars, the sun, the planets, and other heavenly bodies. The chief practical applications of astronomy are found in navigation, time, and the calendar.

Geography. The study of geography is probably the best of the specialized branches of physical science for the purposes of general education because it integrates information gained in all of the other physical sciences in terms of some of the vital problems of man which arise in his attempt to adjust himself to his environment.

Two of the branches of geography are physiography, the study of the earth's physical features, and biological geography, the study of life conditions of plants and animals, including man. Economic geography is a special branch of biological geography which deals with man's industries.

Meteorology. Meteorology deals with the study of climate and weather, and its chief application is in the field of weather prediction.

STUDY QUESTIONS

1. Which is the correct way to measure fatalities for comparing the relative safety of travel by airplane and railroad: (*a*) the number of fatalities per passenger-hour, (*b*) the number of fatalities per passenger-mile, or (*c*) the number of fatalities for trips between two identical points by each method of transportation? Which method of measuring would favor the railroad, which would favor the airplane, and which would tell the truth, and why?
2. Is it true that "figures never lie"?
3. Why is it said that "you can prove anything by statistics"?
4. Why are some straw votes such as the Gallup poll more accurate than others?
5. Would it be possible to take a poll that would be cheaper than, but just as accurate as, a general election in determining the desire of the entire population?
6. What is the business of mathematics?
7. Why are mathematical tools never absolute?
8. What is the business of statistics?
9. What are the fundamental physical sciences?
10. Why do we have "sciences" instead of "Science"?
11. What are the three main types of sciences? Which is the most complex?
12. List three sciences in each of the three divisions of Science.
13. List the most important sciences in the order of their historical development.

UNIT I

SECTION 6

STRAIGHT THINKING IS ESSENTIAL TO THE PURSUIT OF TRUTH

Experimentation does not absolve the scientist from thinking. — Freeman.

Introduction.

The mental side of problem-solving is concerned with initial planning, devising changes in plans in the light of unexpected difficulties or developments, and finally interpreting the data obtained. Mental effort can economize and direct and should accompany and supplement experimentation. Failures are due to lack of insight as well as to lack of observation.

The majority of people think that they think, when they are actually reacting to propaganda in the manner that the cunning propagandists intend them to react. We are all slaves until we learn to think for ourselves. While thinking is an essential step in the scientific method, it is an art; and, like all arts, it has to be learned and then perfected by much practice.

Reasoning, like any other art, cannot come in any way except by doing. One does not learn to play the piano or to paint pictures by reading or talking about a set of rules.

Logical Reasoning Is a Difficult Art Which Results Only from Rigorous Discipline of the Mind.

Reasoning is a process of association of experiences. It leads to truth only when reliable data are fed into the mind. It is the main business of the mind to scrutinize every bit of data of which it becomes aware, to be alert to new data, and deliberately to plan experiments to obtain new data.

Many tests of logical thinking have been developed, but no one knows whether poor thinking is the result of poor use of the mind in scrutinizing and obtaining data or the result of the lack of ability in associating ideas. One might venture the guess that the wrong number is obtained more often because of errors in dialing the telephone than because of errors in making the proper connections in the telephone exchange.

In general, it seems likely that straight thinking results from a deliberate conscious effort to eliminate errors in observation and from much practice in the associational processes of the mind.

There Are Many Obstacles to Be Overcome in Logical Thinking.

1. Confused Thinking Results from the Lack of Careful Definitions. Names are not objects and can never adequately represent objects. Neither can definitions adequately describe experiences, because no two people have identical experiences. Thus it is common experience for many people to use the same term while each one thinks of something different.

It is interesting to note that the majority of arguments disappear when two opponents agree upon a definition. The majority of differences of opinion may be traced to differences in meaning attached to common words by people.

The language of Science is filled with thousands of words especially coined to express new ideas for which no adequate words were previously available. These words have very precise meanings and give a great deal of trouble to beginning students before they learn to use them correctly. Scientists are understood by their fellow-scientists because there is no vagueness concerning the meaning of the terms that they use. It has become necessary to invent thousands of new words which are so technical that no one can understand them except fellow-scientists trained in the same field. The doctor says that we have "injured the tibia" when we have hurt our shin. The sailor calls the left side of the ship the "port side." Every specialist—the preacher, the lawyer, the banker, the machinist, the baker, or the sportsman—has his own terminology. It is remarkable that we understand each other as well as we do. This development of a host of new words has also made it necessary for a large amount of the time spent in scientific training to be used in mastering this technical vocabulary.

2. Pseudo-statistical Thinking. Many people are rightly very skeptical concerning statistical reasoning because they have seen so many examples of statistics which have been carefully selected so as to lead to a predetermined conclusion.

It is quite possible to find instances or figures which seem to support either side of a question. The important source of crookedness in statistical thinking is the failure to obtain all of the data. One could discover many examples of cruelty among the Russian people and thus arrive at the conclusion that *all* Russians are cruel. One must be very careful not to change *some* to *all* in his thinking. It is quite true that *some* Russian people are cruel. Some American people are also

cruel. The conclusion that *all* Russian people are cruel is based on inadequate and selected data. There are plenty of data to show that many Russian people are not cruel. Proof by selected instances, convincing as it may sound, is no proof at all. Beware of this pitfall.

A man has two legs.
John Smith has only one leg.
Therefore, John Smith is a woman.

This is an extreme example of crooked thinking. In the first place, the inference is that *all* rather than *some* men have two legs. There is also inferred the idea that *man* refers to *male* and that *only* males have two legs. Many examples of reasoning in the world today are just as crooked as this one.

3. Speculative Thinking Not Based on Adequate Data Is Usually Crooked Thinking. In order to arrive at correct conclusions, we must have an adequate supply of data as well as accurate methods of thought.

Speculative thinking is valuable in suggesting what might be true, but it must never be used in deciding what is true.

The danger of speculative thinking is that it is easy to think that what *may* be true actually *is* true.

4. Repetition Is Often Confused with Proof. The Tibetan worshiper turns his prayer wheel, each turn serving as a prayer, on the theory that a prayer repeated often enough will be answered. One can convince himself or others that a given statement is true if he repeats it often enough.

Advertisers depend upon repetition a great deal, knowing that even an obvious falsehood will be accepted by the majority of the people if it is repeated often enough.

5. Prejudices Lead to That Kind of Crooked Thinking Which Is Often Called Rationalization. Rationalization represents reasoning at its worst because the information furnished the mind has been highly selected on the basis of emotions.

Prejudices are personal obstacles which make us unwilling to think straight. Even the most logical mind using correct data may arrive at incorrect conclusions regarding questions in which his own interests are deeply involved. The most logical man may be wrong in his conclusions if his premises are "slanted," and the most illogical man may be right in his "conclusions." Rationalization is the offering of a logical reason for doing something although this reason is not the real one.

The unfortunate thing is that prejudiced people believe that their ideas are perfectly rational, and the deeper the emotional basis of the prejudice the more tenaciously will the idea be held. When our hidden desires lead us to accept a given idea, our minds invariably furnish us

with a rational set of reasons to support it. A boy who wants a bicycle or a girl who wants a new dress will soon be able to present very convincing arguments to back up these desires. Any arguments to the contrary are brushed aside as being irrelevant because they are not liked. This process of unconsciously selecting only those facts which support an idea precious to us is called *rationalization*.

A test of whether a person's conclusions are prejudiced or not is that of determining whether he will show anger when the bases for his conclusions are questioned.

A still more stringent test of prejudiced thinking is that of determining whether or not a person is particularly pleased with a speech or bit of writing. It is a common experience to experience pleasure when we discover people who agree with our own point of view.

One possible cure for this prejudiced thinking is to develop the habit of arguing with those who agree with us and of trying to understand why still other people disagree with us. Deliberate effort should be made to expose ourselves to points of view radically different from our own, not with the idea of strengthening our own points of view, but rather to discover the areas in which both points of view agree and to reconsider our ideas in the light of the added information obtained.

Many politicians and preachers and the majority of speakers and writers try to influence you not by an appeal to reason but by the use of "color words" (words carrying a high emotional charge).

There is no objection to the use of color words to try to sell ideas to others. The thing to avoid in the use of color words is the attempt to put over an idea not justified by the data that one is presenting. If you ever catch yourself thinking in terms of highly charged, emotional words, you should recognize that you are already well along the way to that kind of crooked thinking which is called emotional thinking.

The choice of the following color words depends upon whether you are for or against something.

For	*Against*
firm	obstinate or pig-headed
eloquent	fanatical
statesman	demagogue
sound	crackpot
plan	panacea
kill	assassinate
loyalist	rebel or insurgent
open-minded	radical
constitutional	revolutionary
heroism	ruthless savagery

A very useful exercise in training yourself to recognize color words and to be on your guard lest you be influenced by them is the analysis of newspaper articles, radio addresses, sermons, political speeches, etc., to discover what color words are used. Then try to discover from these color words what the author or speaker wants you to think, and, if possible, locate information concerning him in order to determine why he wants you to think in that way. Try removing all of the color words and see what content there is left.

6. Incautious Conclusions Are Typical of Crooked Thinking. It is very easy to arrive at extreme conclusions not justified by the available data. Any writer or speaker lays himself open to criticism. Skillful debaters sometimes seek to drive their opponents to defend more extreme positions than they intended to by contradicting their moderate statements. Many good cases and deserving causes are lost because their proponents were incautious enough to make overstatements.

7. Compromise Is Often Expedient, but Not Necessarily Straight, Thinking. A frequent device to win support for a given cause is to assert that it is a compromise between two extreme positions which keeps all of the good and none of the bad of these extremes.

Many people decide a course of action only after studying what other people do under similar circumstances and then try to steer a middle course. Such a procedure avoids argument, but it does not represent an honest attempt to arrive at the truth.

Suppose that one person says that two and two make four, while another person says that two and two make ten. Obviously a compromise between these views, namely, that two and two make seven, would not represent the truth.

8. "Either-or" Thinking Is Usually Very Crooked Thinking. Nature cannot be pigeon-holed. There is no sharp line which divides plants from animals, men from women, white from black, hot from cold, winter from summer, etc. No person is wholly sane or insane, good or bad, intelligent or unintelligent, conservative or radical.

Do not allow yourself to fall into the trap which uses "either-or" for the bait, because it is almost certain to lead you to unsound conclusions.

On the other hand one must not get the idea that differences do not exist because there are no sharp boundaries.

9. Reasoning by Authority Is a Good Tool Wrongly Used by Crooked Thinkers. From the time of the great advances in knowledge made by the Greeks down through a thousand years or more to the Renaissance, most of the reasoning was based on premises established by authority rather than experience.

Today no one can hope to be able to check all data experimentally. It is very important, therefore, that you should learn how to select data based on adequate experimental evidence.

People pay more attention to what authorities think or say than to why they think what they do. Some of our very best authorities in special fields have been sought after for statements concerning almost everything under the sun, with the result that they have even come to regard themselves as authorities. Your first lesson in seeking authorities is to beware of the person, regardless of how great his reputation is, if he considers himself to be an authority. Your second lesson is to look for the reasons for the statements made by the authorities. Real authorities seldom make statements without outlining the evidence upon which they are based.

A real authority should know his subject well enough so that he can present it clearly to nontechnical listeners. When you do not understand a technical statement, ask to have it made clear to you. If this request meets with a loss of temper, ridicule, or another flood of technical jargon, either set down the speaker as an uneducated specialist or a quack. In neither case can he be of use to you.

10. Inconsequential Arguments Abound in Crooked Thinking. Carelessness, thoughtlessness, and laziness often cause people to believe or state conclusions which are not justified by the reasons given to support them.

A certain lubricating oil for automobiles is advertised to "last longer" and reduce knocks. The inference that one is supposed to reach is that this oil would be the best lubricant available for the engine. Actually, emery powder would last longer, and lead tetraethyl would be better for reducing knocks, but neither would serve as a lubricant.

The remedy for this kind of crooked thinking is to ask yourself or others to make clear just how one fact or idea proves that the second one is true.

11. Reasoning by Analogy May Easily Become Crooked.

> One can predict as successfully whether a motor is good, bad, or absent, by examining the hood as he can tell whether the individual is a genius, lunatic, or imbecile by examining the skull. — Moss.

Many people reason by analogy that, if a person has a strong jaw, he has a strong character or is quite determined. A broad or high forehead is frequently thought to be a sure indicator of broad understanding or high intelligence.

One must use analogies with *caution*, because they tend to cause people to arrive at conclusions without checking the data upon which they are based.

STUDY QUESTIONS

1. Criticize the following Miscellaneous Fallacies taken from A. Wolf, *Exercises in Logic and Scientific Method,* The Macmillan Co.

   (1) A vacuum is impossible, for two bodies must touch if there is nothing between them.
   (2) Human life will at some time disappear from the earth, for all men must die.
   (3) To be wealthy is not to be healthy; not to be healthy is to be miserable; therefore, to be wealthy is to be miserable.
   (4) When any condition of life is empty of evil, we easily imagine it to be full of good.
   (5) The proportion of inmates in our asylums who can read and write is very high, from which we may infer that education is among the causes of insanity.

2. Criticize the statement, "Effects always follow causes. The disturbance of the air in front of . . . a moving automobile is the cause of the automobile."
3. Criticize the statement, "He is rich, for he has plenty of time; and 'time is money.'"
4. Is the following conclusion logical? Why or why not? "Whoever has virtue has good; good includes freedom; therefore the virtuous man alone is free."
5. Is propaganda always undesirable?
6. Compare propaganda with disinterested instruction.
7. Show the fallacy in the following argument:

   All Men Are Liars
   Therefore he was a liar
   Therefore, what he said was not true
   Therefore, all men are not liars
   But if he were not a liar
   What he said was true —
   "All men are liars."

8. List some examples of the use of repetition in radio advertising.
9. Make a list of the most popular ideas today and show how these are the means between two extremes. Which extreme is more likely to be correct than the compromise which is so popular?
10. When is a person a capitalist?
11. When is a person a radical?
12. When is a sheet of paper white?
13. List as many of the common slogans and proverbs of today as you can, and try to show that there are many situations and many details in which they are not true. How many of these slogans are true with respect to the circumstances in which they were first used?
14. Can you suggest any exceptions to the following statements?

   "Virtue is its own reward."
   "Americans are dollar-chasers."
   "Europeans are degenerate."
   "The Germans were responsible for the World War."
   "The World War was fought to end war and to make the world safe for democracy."
   "Be wise and alkalize."
   "All men are born equal."

15. Are advertising testimonials examples of crooked thinking? If so, what kind?
16. Make a scrapbook or series of posters showing how reasoning by authority is a path to untruth employed by advertisers.
17. Does the fact that "everybody says a given thing is so" make it so? Why or why not?
18. Should you treat your teacher as an authority? Discuss.
19. Why is the atmosphere of the lecture platform not favorable to intellectual honesty?
20. Try to find examples of inconsequent argument in advertisements.
21. Try to discover examples of irrelevant data in answers given to questions by yourself and your fellow students.
22. Examine "letters from the people" in newspapers for other such examples.

UNIT II

THE UNIVERSE IS A VAST SYSTEM OF PARTS MOVING AND CHANGING UNDER THE INFLUENCE OF A FLOW OF ENERGY

INTRODUCTION TO UNIT II

The study of man's external world reveals the story of an expanding universe. Man's curiosity, aided by a marvelous array of instruments, which have been constantly improved as Science and technology have developed, has extended his vision farther and farther out into space. No longer is the world considered to be the center of the universe.

Today the earth is known to be but one of the smaller cosmic bodies, called planets, revolving about an ordinary star. This star, the sun, is but one of billions of stars moving in a system of stars, which we call our universe.[1] Beyond the confines of our own universe there seem to be other universes or even systems of universes.

As man's knowledge of the universe has expanded, the earth has shrunk in prominence to the point where it has become an inconspicuous speck in the cosmic scheme of things. On the other hand, it appears that the earth, formed perhaps by one of the rare cosmic collisions, is a unique body in that it is able to support life as we know it.

[1] *Universe and galaxy* are used here synonymously. The more common use of the term *universe* is that in which we speak of *the* universe when referring to the sum total of all galaxies and supergalaxies.

UNIT II

SECTION 1

MANY IDEAS CONCERNING THE NATURE OF THE UNIVERSE WERE DEVELOPED FROM THE TIME OF THE EARLY GREEKS TO THAT OF GALILEO

Introduction.

Astronomy is one of the oldest of the sciences; its beginnings are lost in antiquity. The origin of the arbitrary division of the calendar into weeks has been lost, but the fact that the days of the week were associated with heavenly bodies is well attested by their names; Sunday (sun's day), Saturday (Saturn's day), etc.

Very early in the history of civilization man must have felt the need for methods of reckoning time, and it is probable that astronomy developed out of this need. Ancient Chinese, Babylonian, and Egyptian records show that considerable attention was given to the study of the heavenly bodies which were visible to the unaided eye.

The Ideas of Ancient Astrology Were Founded on a Little Evidence and Much Superstition.

Early explanations of natural phenomena all centered around the idea that everything had a soul like that of man. Every object, animate or inanimate, had thoughts and feelings and was friendly or unfriendly to man. This concept called for the medicine-man, or the priest, to evolve and perform certain occult rites to keep these thousands of unseen forces friendly. Gradually the belief grew that these priests were endowed with the powers of foretelling future events; and, as soothsayers and intermediaries between man and the unseen forces, they became the valued advisers of the people's rulers.

It is not surprising that man came to consider the stars and planets as living deities, who controlled the destinies of man, and that he worshiped them as such.

Long before the time of Christ, astronomical measurements were made to determine the time for annual national and social events and to predict positions of the stars favorable to important undertakings. This growth of astronomy naturally led to the early high development

of those parts of mathematics (geometry especially) which are useful to astronomy.

Even in this enlightened age so many people believe in astrology and horoscopes that about 20 per cent of the newspapers print daily columns devoted to this most ancient pseudo-science.

The code of Standard Astrology states that "a precise astrological opinion cannot honestly be rendered with reference to an individual unless it is based upon a horoscope for the year, month, day and time of day, plus corrected geographical location of the place of birth of the individual." How, then, could forecasts in newspapers or magazines be of any value? On the other hand, are such horoscopes less valuable than those specially prepared for individuals?

One of the errors of astrology is that it requires that planets with a considerable degree of similarity would affect human affairs in entirely dissimilar ways.

Modern Astrology Still Flourishes As a Substitute for Problem-solving.

The following statements were taken from a report of the Executive Council of the Society for Psychological Study of Social Issues:

> The principal reason why people turn to astrology and to kindred superstitions is that they lack in their own lives the resources necessary to solve serious personal problems confronting them. Feeling blocked and bewildered they yield to the pleasant suggestion that a golden key is at hand — a simple solution — an ever-present help in time of trouble. . . .
>
> By offering the public the horoscope as a substitute for honest and sustained thinking, astrologers have been guilty of playing upon the human tendency to take easy rather than difficult paths.

The Babylonians and Egyptians Made Some Valuable Observations and Derived Some Interesting Conclusions Concerning the Nature of the Universe.

The Babylonians pictured the universe to be a closed chamber, with the earth as its floor. Around the earth lay a moat of water, beyond which stood high mountains supporting the dome of the heavens. The Babylonians recognized eclipses and predicted the times that they would occur. They even fixed the length of the year as $365\frac{1}{4}$ days, which represented an error of only eleven minutes in excess of our most accurate modern measurements.

The Hebrews' concept of the universe, probably influenced by the Babylonians, was that there was a heavenly expanse resting on pillars and containing windows through which waters that surrounded the firmament could reach the earth. It is obvious that their ideas were based on less information than we have available today.

The Greeks, from Thales to Ptolemy, Made Many Discoveries and Formulated Theories That Were Accepted for Nearly Two Thousand Years.

No doubt there were many thinkers among the primitive astronomers of Chaldea, Babylonia, China, Egypt, and India; among the outstanding thinkers known to history was *Thales* of Miletus, who died in 546 B.C. He has been called the founder of Greek astronomy. Thales was a merchant, statesman, engineer, mathematician, and astronomer. He taught the Greek sailors to guide their ships by the polar star and observed the natural division of the year into four seasons by the regular recurrence of the longest and shortest days of the year and of the two intervening days when the days and nights were of equal length. He successfully predicted an eclipse of the sun. He believed the stars to be self-luminous bodies and the moonlight to be but a reflection from the sun. He taught that the earth was a flat disk floating on water.

Anaximander, a contemporary of Thales, was the first man to recognize that the heavens revolve around the polar star and to teach that the visible dome of the sky is half of a complete sphere whose center is the earth. For many centuries after his time the earth was considered to be the center of the universe. Anaximander is also said to have introduced into Greece the sundial, consisting of an upright rod (style, or gnomon) on a horizontal ground.

Anaximenes (died 526 B.C.) thought that all matter was composed of one primordial substance, water. When water became rarefied, it was fire; when condensed, it was earth.

Pythagoras (died about 500 B.C.) thought that there were four elements[1]—earth, water, air, and fire—instead of only one and drew his picture of the universe with this idea in mind. The earth was recognized by him to be a sphere, whose rotation explained the apparent rotation of the heavens.

It is unnecessary to recite all of the fanciful conceptions of the universe developed by the early philosophers of Greece. Inasmuch as they were not greatly troubled with the necessity of testing their theories, it is a wonder that they did not go farther astray.

Socrates (died 399 B.C.), who regarded introspection as the only worthy type of study, influenced men to turn their attention away from the investigation of nature. His pupil, *Plato* (died 384 B.C.), condemned experiment as an impious and base art.

The next Greek of great importance was *Aristotle* (died 322 B.C.), who was one of the greatest organizers and generalizers the world has ever known. So great was the encyclopedia of knowledge compiled by him that he was looked upon as the final authority in many fields of

knowledge for nearly two thousand years. One of his greatest contributions was the creation of the inductive method of reasoning and the working out of the principles of logic. Aristotle improved nearly every field of learning he touched except those of physics and astronomy. He considered the earth to be a sphere in the center of the universe and taught that the planets were supernatural beings entirely unlike the the earth. Aristotle added a fifth element,[1] ether, which was supposed to move in circles. He rejected the ideas of previous philosophers that matter could be divided into ultimate particles called atoms.

Of all the Greeks, *Aristarchus* (died 230 B.C.) held the most modern ideas of astronomy. He taught that the spherical earth and the planets revolved about the sun. He concluded that the sun was about twenty times more distant from the earth than the moon. The actual ratio is about 1 to 400, but his errors were due to inadequate instruments; the principles of his experiments were sound. He accounted for the relative immobility of the stars by rightly assuming that they were very much farther away than the sun. Unfortunately the experiments of Aristarchus were rejected for the teaching of Aristotle.

Eratosthenes (died about 195 B.C.) was the first man to measure the size of the earth on the assumption that it was a sphere. He noted that at noon on June 21 at Syene, Egypt, the sun was directly overhead and that exactly a year later at Alexandria the sun was a little more than 7 degrees south of the line passing directly overhead. He concluded that this was due to the fact that the earth was round. Inasmuch as the distance between these two cities (about 480 miles by his measurements) represented 7/360 of the entire circumference of the earth, he figured the circumference to be about 24,000 miles, which is within about 900 miles of the present accepted value for the circumference at the equator.

Hipparchus (died 125 B.C.) was the last of the great Greek astronomers. He catalogued about 1080 stars, classified according to their brightness, and mapped the course of the sun among the stars. His measurements of the size of the moon and its distance from the earth were within about 10 per cent of present-day values. He discovered the precession of the equinoxes (see page 98) and determined its amount.

The next great man was *Claudius Ptolemy*, a Greek born in Egypt, who, between the years 127 and 151 A.D., made observations in Alexandria, the center of Hellenic culture for centuries. On the basis of

[1] When the ancients used the word "element," it meant "elementary quality" rather than "elementary substance," which is the modern meaning of the word, first clearly defined by Lavoisier.

these observations he worked out a system of astronomy that dominated the minds of men for the next thirteen centuries. His great contribution was the compilation of his *Almagest*, or encyclopedia of astronomy, which preserved the work of Hipparchus.

Ptolemy believed that the earth is the center of the universe. He also erroneously believed that the earth is stationary, but he was correct in his assumption that the earth is a sphere, balanced without supports in space. He concluded that the fixed stars were fastened to the inside of a vast dome that revolved about the earth once every twenty-four hours. The planets supposedly moved in independent orbits between the earth and this star-studded dome. His system was so satisfactory that it was widely accepted and never seriously challenged until the time of *Copernicus*, thirteen centuries later.

The thirteen hundred years following Ptolemy were a period of retrogression, in which people returned to the old astrology, and, forgetting the relatively advanced teachings of Ptolemy, generally considered the earth to be flat.

Copernicus Was the First of the Renaissance Astronomers.

Nikolaus Copernicus (1473–1543) was a skilled painter and student of medicine, mathematics, and astronomy. He taught from the still dominant *Almagest* and was greatly influenced by the teachings of Aristarchus. Fortunately he did not accept traditional theories without question but made observations of the stars for himself. He found so many errors in the Ptolemaic tables that he came to distrust all of Ptolemy's teachings.

In 1507, he wrote his famous book *De Revolutionibus Orbium Caelestium* ("Concerning the Revolutions of the Heavenly Bodies"). His main thesis was that the sun is the center of the solar system and that the earth is but one of the planets revolving around the sun. He also advanced the modern concepts that the moon revolves around the earth, accompanying it in its revolution around the sun, and that the earth turns on its axis from west to east, thus accounting for day and night and the apparent motion of the stars.

Other Renaissance Astronomers.

Copernicus' follower, *Bruno* (1548–1600), went even farther and stated that the universe is infinite and that the stars are scattered throughout space. He was regarded as a heretic, however, and was burned at the stake in 1600.

Tycho Brahe (1546–1601), whose interest in astronomy was aroused by an eclipse of the sun coming at the exact time predicted in 1560,

spent his life making untiring and much more accurate measurements of the positions of the stars and planets than had before been made. He designed and built a large observatory equipped with the best instruments. He rejected Copernicus' system but devised one of his own, in which the sun revolved about a stationary earth and the planets, in turn, revolved about the sun.

Johann Kepler (1571–1630), a student of Tycho's who fell heir to his observations, became a convert to the Copernican system. Kepler's main contribution was the discovery of three laws which laid the foundation for the great work of Newton. Kepler's laws may be stated as follows:

1. The planets travel in paths which are ellipses with the sun at one focus.
2. A planet so moves that an imaginary line drawn from it to the sun sweeps over equal areas in equal intervals of time.
3. The squares of the times that the planets require to make complete revolutions about the sun are proportional to the cubes of their mean distances from the sun.

According to these laws a planet moves fastest when it is nearest the sun and slowest when farthest from the sun. It remained for Newton to explain this phenomenon.

Galileo Challenged Authority with His Telescope.

The intellectuals of this time (about 1600) found their teachings challenged by the concept of the Copernican system and, not being open-minded, brought pressure to bear on the not unwilling churchmen for a protest. Therefore *Galileo* (1564–1642), the first of the moderns, met with much opposition.

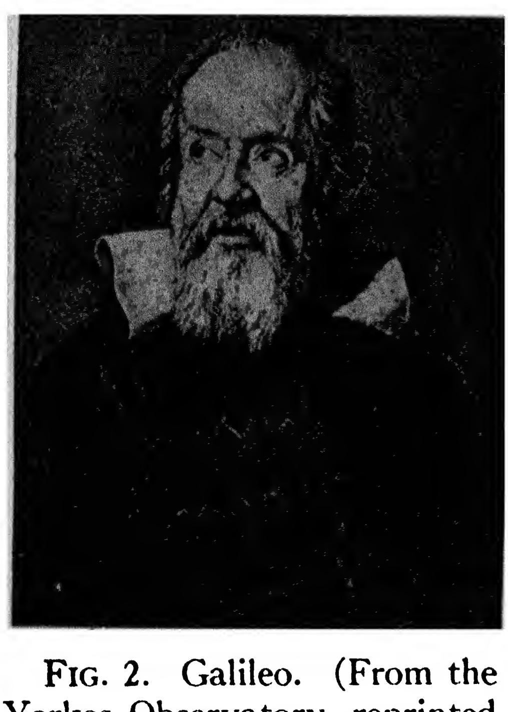


FIG. 2. Galileo. (From the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

Galileo's great contribution to astronomy was the construction of the telescope and its application to the study of the heavenly bodies. It is quite probable that he got the idea for it from a Belgian spectacle-maker, *Lippershey*, who had invented combinations of lenses to magnify distant objects. By applying his knowledge of optics, he built a telescope for himself which would magnify 33 diameters. He established the validity of the Copernican theory by his discovery

of the revolution of the four largest moons which revolve around Jupiter. He discovered mountains on the moon and spots on the sun by which he could detect its rotation. The Milky Way was shown to consist of myriads of faint stars. And what a thrill it must have been when he first saw Saturn's gorgeous rings!

Galileo was the first experimenter to seek facts and accept his findings as such without trying to give them unwarranted meaning or trying to fit them into an already existing philosophy.

In the sixteenth century the citizens of Geneva decided: "For once and forever, in no branch of learning shall any one stray from the philosophy of Aristotle." Such was the spirit of the age in which Galileo lived, and Galileo's greatest contribution was his challenge to authority. Galileo asked people to experiment and base their conclusions on observations rather than on the statements of Aristotle.

STUDY QUESTIONS

1. Why was the Copernican theory of the solar system not generally accepted when it was advanced? Compare this with the modern treatment of new theories.
2. What were the Babylonians' ideas concerning the stars?
3. Give a brief outline of your present conception of the universe.
4. List some of the astronomical ideas of the Greeks.
5. Give the main points of Ptolemy's ideas concerning the universe. Which of these were erroneous?
6. What new concepts concerning the nature of the universe did Copernicus introduce?
7. What led Copernicus to reach his conclusions concerning the solar system?
8. What led Galileo to reach his conclusions concerning the solar system?
9. Why were the ancient conceptions of the universe so inaccurate?
10. Upon what observations did Thales recognize a natural division of the year into four seasons?
11. How did Thales account for the luminosity of the moon?
12. In what two entirely different ways did some of the Greek philosophers explain the apparent rotation of the heavens?
13. Why did Galileo meet with much opposition to his ideas?
14. What were the contributions of each of the following men to astronomy? (*a*) Thales, (*b*) Hipparchus, (*c*) Ptolemy, (*d*) Copernicus, (*e*) Brahe.
15. What was the most important contribution of Galileo to Science?
16. What is astrology? Look up the meaning of this word in an encyclopedia. Is astrology a science?
17. What is meant by the statement that astrology is a pseudo-science?
18. Why do people believe in astrology?
19. Visit a local newsstand and find out how many astrology magazines and how many copies of each are sold each month by this stand. What are the prices of these magazines?

20. After the completion of a study of this unit on astronomy, a student wrote, "I was very much interested in this study of astrology." Write a paragraph using this statement as your text.
21. What are the major ideas of astrology?
22. Differentiate between astronomy and astrology.
23. Look up the meaning of the word astronomy in an encyclopedia.
24. State Kepler's three laws of motion.

*

UNIT II

SECTION 2

TELESCOPES HAVE GREATLY EXPANDED MAN'S CONCEPTION OF THE MATERIAL UNIVERSE

Like buried treasures, the outposts of the universe have beckoned to the adventurous from immemorial times. Princes and potentates, political or industrial, equally with men of science, have felt the lure of the uncharted seas of space, and through their provision of instrumental means the sphere of exploration has rapidly widened.[1] — George Ellery Hale.

Introduction.

Galileo's application of the telescope to astronomy was very significant because it extended the observational basis for generalizations concerning the heavenly bodies. It revealed an unknown universe, whose vast proportions have been expanded with each improvement in the telescope. This section deals with the development of the telescope and the information thus made available.

Telescopes Have Been Greatly Improved Since the Time of Galileo.

Galileo's telescope was a refracting type, based on the extremely simple, familiar principle that a convex lens will bring light to a focus by bending (refracting) it. There are two lenses in a refracting telescope — one, the object glass, brings the light to a focus; the other, the

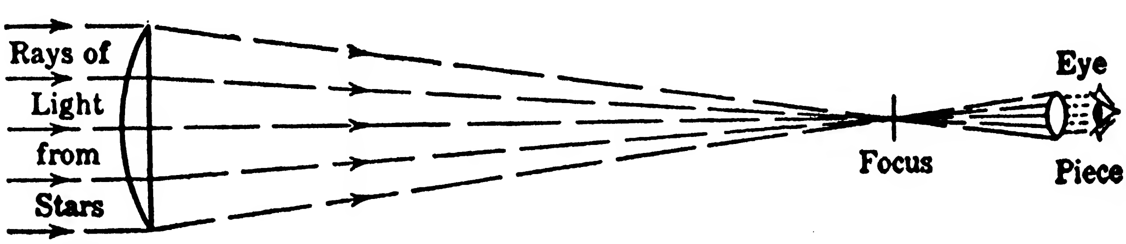


FIG. 3. The principle of the refracting telescope.

eyepiece, magnifies the image. The focal length of the magnifier, or eyepiece, in relation to the focal length of the objective, determines the magnifying power of the telescope, and the amount of magnification may be changed by merely changing the eyepiece.

The telescope concentrates the light which is too faint to be visible

[1] *Signals from the Stars*, Charles Scribner's Sons, New York, 1931.

to the naked eye; a five-inch object glass has about 400 times the area of the pupil of the eye (which is about $\frac{1}{4}$ inch in diameter) and can collect about 400 times as much light.

The largest refractor in the world is the Yerkes telescope at Lake Geneva, Wisconsin. The Yerkes 40-inch telescope will collect about 25,600 times as much light as the eye and thus render visible stars that are 25,600 times too distant to be visible to the naked eye.

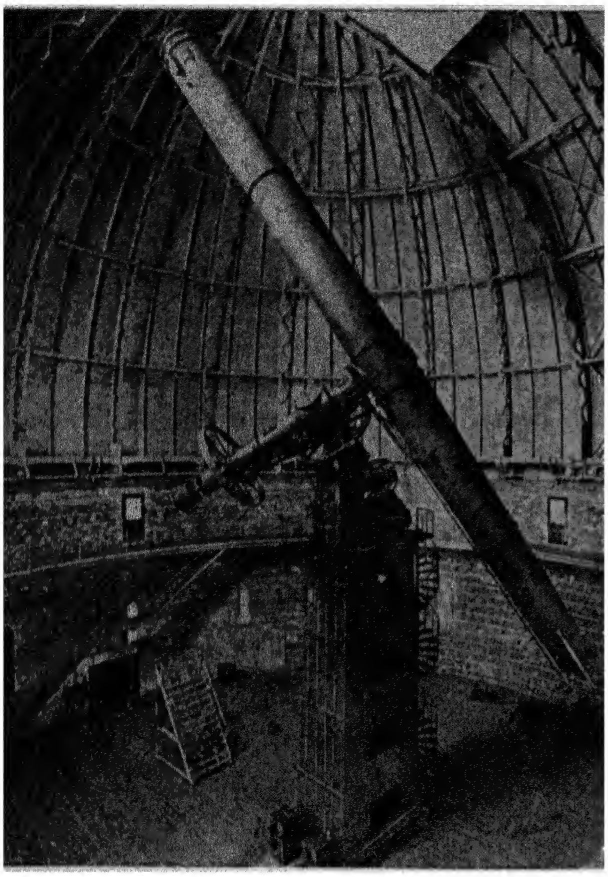


FIG. 4. The 40-inch telescope at the Yerkes Observatory with rising floor at its lowest position. (Photograph from the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

The next largest refracting telescope is the 36-inch Lick telescope at the Lick Observatory on Mount Hamilton near San Jose, California. *James Lick* bequeathed three million dollars to build the telescope and observatory, which was completed in 1888. The object glass for this telescope was cast in France and polished in America.

Just as light is bent as it passes from air through glass, so it is bent by passing from less dense into more dense air (cold or hot). Variations in the moisture content of the air likewise cause bending of the light. Everyone has observed how the air seems to quiver over a hot surface, lending a soft, feathery-edged, blurred appearance to distant trees and other objects. The unaided eye can observe that the stars near the horizon seem to flicker because of the optical aberrations produced by the varying strata of air. To reduce this error as far as possible, telescopes are located, whenever possible, on mountains whose locations have been selected after a great deal of investigation. Another important point to consider in location is to place the telescope where light from large cities will not interfere and where the least number of cloudy days will be experienced.

A good telescope cannot be kept in a heated dome in winter, because the warm air escaping through the opening will produce a wavering of air which makes observations impossible, while variations in the density and curvature of the objective lens due to temperature variations will produce even greater errors.

The image formed by a simple lens is subject to a number of defects, called aberrations; for example, light of different colors is refracted by different amounts with the result that these different colors are

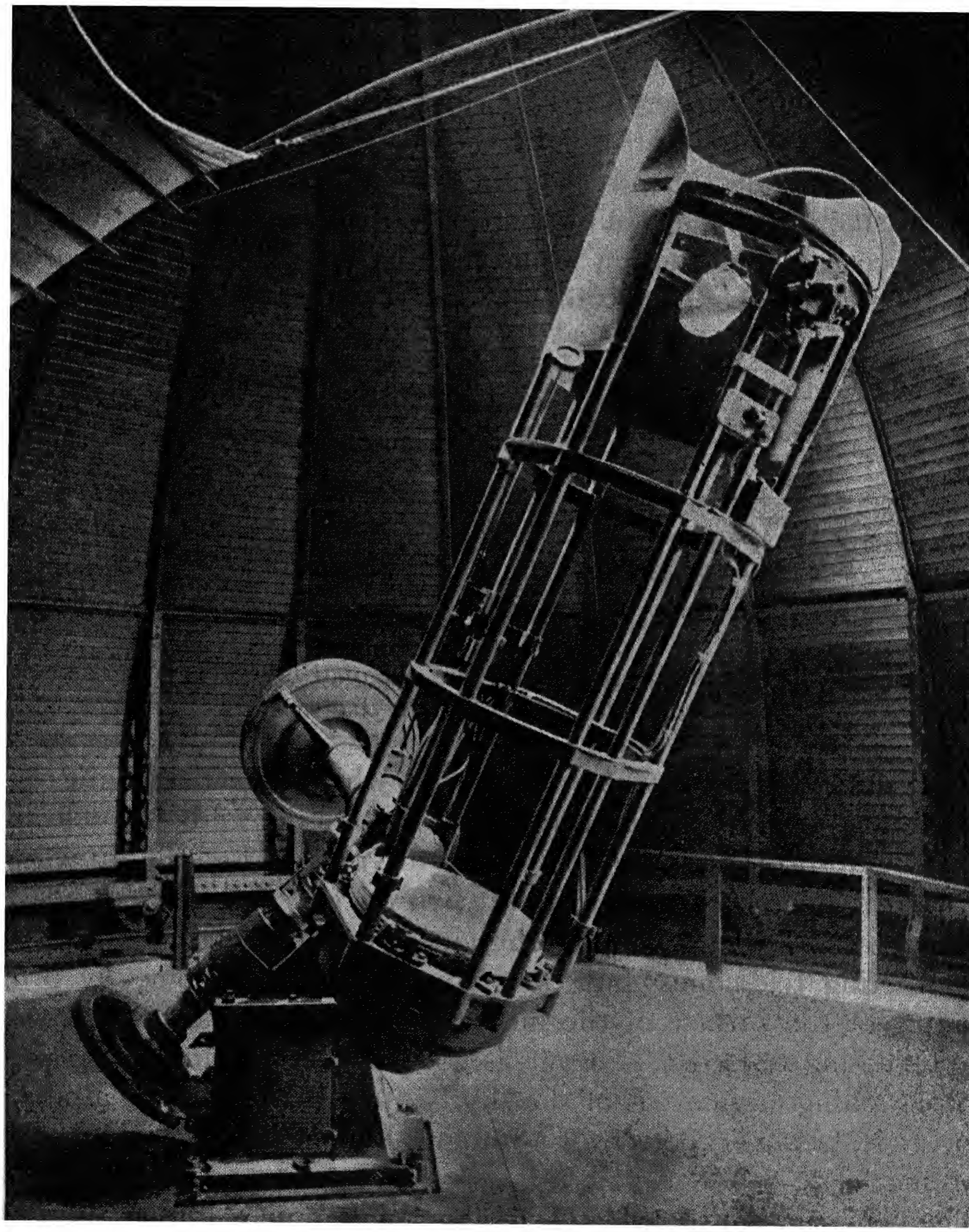


FIG. 5. The 24-inch reflecting telescope of the Yerkes Observatory. (An astronomical photograph from the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

not brought to a focus in the same plane. Another type of aberration, known as spherical aberration, is the blurring of an image toward the edge of the field of view. Both of these aberrations may be reduced

by use of a compound lens which is made up of a number of different lenses ground to different shapes.

The best magnification that Galileo could obtain with a simple objective was never greater than one hundredfold, while modern objective lenses permit good images 25,000 times this value.

Compound lenses increase the loss of light both by absorption and reflection; and, of course, the larger the lens the thicker it becomes, and the greater is the amount of light absorbed.

Most of the objections to larger refracting telescopes could be dealt with satisfactorily today; but larger telescopes would be very unwieldy, and the cost of construction would be prohibitive. Refractors are the best type of telescopes as far as smaller instruments are concerned.

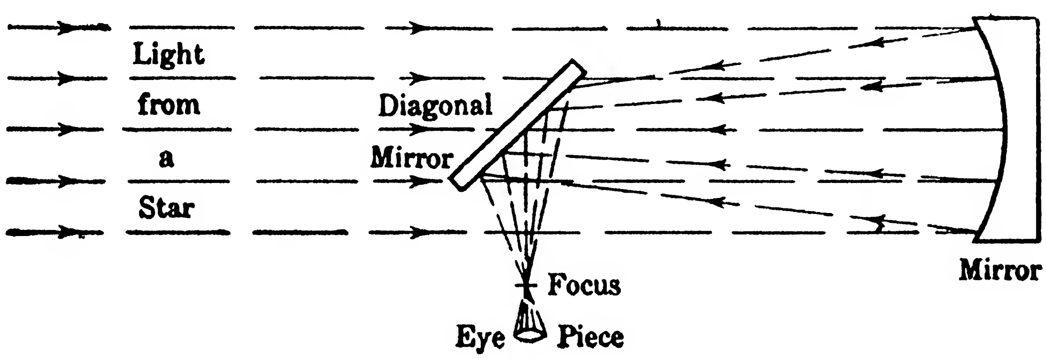


FIG. 6. The principle of the reflector. The diagonal mirror is relatively much smaller than shown in the diagram.

Larger telescopes employ concave mirrors which reflect the light rather than refract it as the refracting object glasses do, and thus less light is lost by absorption. All of the colors are reflected at the same angle so that there is no chromatic aberration in reflecting telescopes. The spherical aberrations are more pronounced in reflecting telescopes than in refracting telescopes, but they are partially overcome by proper grinding of the surface of the mirror to a concave paraboloid shape. The reflecting telescope is never as good as a refracting telescope for photographing large areas of the sky because of this spherical aberration. It is, however, better for photographing small areas because it is achromatic.

The construction of reflecting telescopes is much simpler than that of refracting telescopes because only one surface has to be shaped, rather than four or more surfaces, in the compound lens, for example, and the color or transparency of the glass is of no importance because the light does not pass through it. A mirror may be supported from the back, while a refracting lens has to be supported at the edges.

It should be recalled that magnification is controlled by the eyepieces. Why, then, should larger objectives be used? The objective

has two functions, (1) resolving-power, and (2) light-gathering power. Resolving-power refers to the ability to produce an image showing very fine detail. Increasing the size of the objective increases the light-gathering power of a telescope just as the dilating of the pupil of the eye enables one to see better in poor light. Telescopes enable us to see very distant stars because they gather in so much light from the stars rather than because they magnify the images of the stars. This is the fundamental difference between microscopes and telescopes.

Sir Isaac Newton (1642–1727) constructed the first reflector type of telescope in the attempt to avoid the difficulties presented by the refracting lens.

The first giant reflector, equipped with a 72-inch mirror, was constructed by *Lord Rosse*, in Ireland, in 1845. A crude, unwieldy affair, it had none of the automatic mechanisms of modern telescopes. It had to be twisted about by hand and was kept focused on the object in the same way.

The mechanism of modern telescopes enables them to be kept focused on an object in any predetermined position in the sky with great precision, by means of mechanisms regulated by clocks that move the position of the telescope at the same rate that the earth turns so as to keep the object in view.

The astronomer of today merely presses buttons which set electric motors into action to move the telescope, revolve the dome, and raise or lower the floor surrounding but independent of the telescope and even the platform on which the observer reclines.

The Mount Wilson 100-inch Reflecting Telescope Is One of Man's Most Expensive Scientific Instruments.

The largest telescope in existence in 1936 was the Mount Wilson 100-inch reflector, which has a light-gathering power of 160,000 times that of the human eye. The four and a-half ton, 13-inch-thick mirror for this telescope was cast in France and required four years for the polishing of its surface. As the telescope and its mountings weigh over a hundred tons, it was a real undertaking to transport all of the parts up to the top of Mount Wilson, 5000 feet above Pasadena, California.

The revolving dome of the main observatory is over 100 feet high. The telescope itself is mounted on large hollow cylinders floating in a huge bath of mercury.

Modern Telescopes Have Extended Man's Knowledge of the Universe.

With modern telescopes man has been able to bring into visible or photographic view nearly thirty billion stars, or ten million stars for

every star that is visible to the unaided eye even on the clearest night. It would take about fifty years, counting two to a second without stopping, day and night, to count this number of stars. Each of these stars is a bright sun, pouring forth much more light in many cases than does our own sun (S. Doradus emits 500,000 times as much light as our sun), and yet some of them are so far distant that the light gathered in by the 100-inch reflector becomes visible only by taking time exposures of several nights' length. So far distant are the stars that a unit of measurement, the light-year, has been devised. This is about 6,000,000,000,000 miles, or the distance light travels in a year at the rate of 186,272 miles per second. Light takes 1.3 seconds to travel from the moon to the earth, and 499 seconds, or 8.3 minutes, to travel from the sun to the earth. It takes light 4.16 years to come to the earth from the nearest star, Alpha Centauri. Only fifteen known stars are within a distance of a dozen light-years. The light from the most distant objects visible with present instruments is now estimated to have started on its way to us about three hundred million years ago.

The 200-inch Reflecting Telescope Ranks as One of the Greatest Technical Achievements of This Generation.

The 200-inch reflecting telescope is the result of the efforts of *George Ellery Hale*, who died in 1938 before it became a reality. It was George Ellery Hale's dream of a 200-inch telescope that brought the $6,000,000 gift from the International Education Board, financed principally by *John D. Rockefeller, Sr.* This giant telescope is located on Mount Palomar, in southern California, and is operated by the California Institute of Technology and the Carnegie Institution of Washington, D. C. The plans for this gigantic instrument have been progressing since 1929.

The most intense radiations from the very hot blue stars are in the ultraviolet portion of the spectrum, while the most intense light from the cool red stars is in the infrared.[1] It was found that silver used on the mirrors of modern telescopes will not reflect the ultraviolet rays, so the technique of coating telescopic mirrors with aluminum, which will reflect the ultraviolet rays, has been perfected. *J. Strong*, of the California Institute of Technology, has already coated the 36-inch reflector of the Lick Observatory [2] and all of the Mount Wilson reflector instruments as a sort of preliminary exercise. There are plans to give an aluminum coat to the 200-inch mirror also. The light-gathering ability of the 200-inch reflector will be 640,000 times that of the human

[1] The different types of stars are described in Section 3 of this Unit.
[2] Do not confuse the 36-inch reflector with the 36-inch refractor at the Lick Observatory.

eye, as compared with 160,000 times for the Mount Wilson 100-inch telescope. The aluminum coating should also greatly increase the total reflected light to which the much-improved photographic emulsions are sensitive, so it is hoped that the new telescope will penetrate three times as far into space as formerly, opening for investigation an unexplored sphere about thirty times the volume now within the range of the Mount Wilson 100-inch reflector.

The 200-inch mirror for this telescope was made of Pyrex glass, a borosilicate glass, and weighs 20 tons. It was cast from a batch of 65 tons of glass after heating it in a furnace for forty days. It was placed in an oven to cool on December 2, 1934, and removed on December 8, 1935. Then followed many tests to determine whether it would be satisfactory or whether another mirror would have to be cast. The mirror was then shipped to California on April 10, 1936, to be polished to an accuracy of "two millionths of an inch." In the final stages, polishers could not work on the mirror more than an hour each day, because it was necessary to test so frequently. Places on the surface that were too high had to be lowered, for there was no means of changing those that were too low, and the lowering could not go too far. Often two or three minutes' work was all that could be done without testing to see whether or not enough had been done. In order to make these tests, the surface had to be cleaned off and dried and then set up for the test. In this process temperature changes were inevitable; and hence, with a large mirror, several hours elapsed before a reliable test reading could be made.

The construction of the mounting for the 200-inch mirror has been a tremendous engineering problem. Five hundred tons of steel had to be fitted together to tolerances in some places as close as two millionths of an inch. The whole mounting is floated on oil and can be moved by exerting only 1/650,000 of a horsepower.

Many Other Giant Telescopes Are in Use.

Important as this large telescope is, it must be remembered that there is a tremendous number of observations to be made and that all observations must be checked as many times as possible by different observers using different instruments located at different places. Other great instruments now in use are: a new 76-inch reflector at the University of Toronto, Canada; a 72-inch reflector at Victoria, British Columbia; a 69-inch reflector at the Perkin Observatory at Delaware, Ohio; an 85-inch reflector at Base Lake, Michigan; and an 80-inch reflector in the $840,000 McDonald Observatory on Mount Locke, Texas. There are at least nineteen other giant reflectors, ranging from

36 inches to 72.5 inches, and more than forty large refractors in use throughout the world.

STUDY QUESTIONS

1. Give the principles of the two types of telescopes.
2. What type of telescope is used at (*a*) the Mount Wilson Observatory, (*b*) the Yerkes Observatory, (*c*) the Lick Observatory?
3. Which type of telescope should be used for observing the details of the surface of the moon, and why should that type be selected?
4. What type of telescope did Galileo use?
5. Why are many telescopes located on mountains?
6. How are modern telescopes kept focused on a given star as the earth moves?
7. What is a light-year?
8. Of what possible value will the 200-inch telescope be to humanity?
9. Why is the 200-inch mirror made from "Pyrex" glass?
10. Why are the largest telescopes reflectors rather than refractors?
11. What determines the magnifying power of a telescope?
12. What are the relative advantages and disadvantages of reflecting and refracting telescopes?
13. What are the functions of the objectives in telescopes?
14. Inasmuch as telescopes do not depend upon magnification to see distant stars, how do they enable us to see stars invisible to the unaided eye?
15. What is spherical aberration, and how is it overcome?
16. What is chromatic aberration, and how is it overcome?
17. What is meant by the resolving-power of a lens?
18. Why are very large refractors less practical than very large reflectors?

UNIT II

SECTION 3

MANY INSTRUMENTS SUPPLEMENT THE TELESCOPE IN EXPLORING THE UNIVERSE

Introduction.

Nowhere is man's ingenuity shown to better advantage than in his invention of instruments to aid him in making observations. In many cases the information obtained requires interpretation in the light of modern knowledge, and it is always possible that, as more knowledge becomes available, these interpretations will have to be changed. It is important, therefore, to keep in mind that the interpretations presented in this section are in some cases several years old and it is quite possible that some of them now need revision.

The Camera Is More Sensitive Than the Eye.

By substituting a camera for the eye, the telescope becomes much more useful, because it not only enables man to gather all of the light from a star for many consecutive hours, but it provides a lasting record which may be studied at leisure and be compared with similar photographs taken from time to time.

The Spectrometer Is One of Man's Most Valuable Instruments.

To Newton we owe the discovery that light rays are bent when they enter a prism, the visible and invisible rays forming a continuous spectrum in which all of the rays originally present are separated. We now know that the rays are separated because the rays of short wave length are bent more than the rays of long wave length as they pass through the prism. If red light rays are absent in the original light rays, there will be a gap in the spectrum where red should occur, and so on for all of the visible and invisible light rays. The invisible short ultraviolet and long infrared rays, as well as the visible rays, may be photographed, so that a camera generally replaces the eye in a spectrometer.

The spectrometer has two tubes, one of which collects a thin beam of light through a narrow slit and renders the light parallel by means of

a "collimating lens." The other tube also contains a lens to carry the image of the spectrum to the eye. As one views the light which is a mixture of all visible light rays through a spectroscope, the resulting spectrum appears as a series of beautiful colors like a cross section of a rainbow.

A continuous spectrum (that produced by light from an incandescent solid or liquid surface) is found to vary in intensity at different positions. This variation in the intensity of different wave lengths is connected with the temperature so that the spectrometer enables one to determine the temperature of an incandescent body by analyzing the light which it emits.

The spectrum obtained from a luminous gas is called a bright-line spectrum because it is not continuous but contains certain narrow lines or bands of color. Inasmuch as light has its origin within the smallest molecular and atomic electrical systems of matter, it is not surprising to learn that the analysis of light from any given source reveals an enormous amount of information concerning that source. There is a definite position for each of the bright lines, which is always the same for the same element of matter. Not only do the elements,[1] such as hydrogen, nitrogen, and helium, show characteristic spectra, but so likewise do many compounds of these elements. By the use of the spectroscope man is thus able to analyze samples of matter on the earth and determine their composition.

Joseph Fraunhofer (1787–1826) observed a number of distinct dark lines of varying width vertically across the continuous spectrum which he obtained with sunlight. He carefully noted the position of about 600 of these lines, which have been named Fraunhofer lines in his honor; but he failed to explain their significance.

Kirchhoff's discovery of bright-line spectra in 1859, coupled with the later momentous discovery that light rays from a luminous gas, when passed through a cool, nonluminous layer of the same gas, would produce dark bands at the exact position of the bright lines produced by the gas under ordinary conditions, provided the key to a vast storehouse of knowledge concerning the universe. At last the Fraunhofer lines were explained. They must have been produced by the passing of the sun's rays through the envelope of cooler gas surrounding the sun, which itself is thought to be a huge mass of luminous gas. The bright-line spectra of known elements on the earth were found to coincide with the position of many of the Fraunhofer lines, so that it was soon learned that such elements as sodium, carbon, iron, copper,

[1] An element is one of the 92 different kinds of matter that cannot be decomposed into simpler kinds of matter by ordinary chemical means.

calcium, nickel, zinc, magnesium, oxygen, hydrogen, and many others were common to both the earth and the sun.

The spectrometer also enables the astronomer to measure *star distances*. The same Fraunhofer lines from different stars were observed to vary in width. By checking these star distances by the method of parallax,[1] it was found that the width of the Fraunhofer lines revealed the intrinsic or actual brightness of a star. Knowing the apparent brightness of a star as measured by means of a telescope and the eye or a photoelectric cell, and knowing its actual brightness as shown by the Fraunhofer lines, it is easy to estimate star distances. One could compute distances on the earth in the same way by the use of lights of equal brightness, such as airplane beacons, and then measuring the apparent brightness of all of the lights in sight. The knowledge of the actual and apparent brightness of the stars enables one to estimate their distance from the earth, for it is known that the intensity of light varies inversely as the square of the distance from the observer.

The velocity of a source of light can also be observed by means of the spectrometer. Here again the Fraunhofer lines or emission lines come into use; they are observed to shift their position slightly. In the study of sound it is found that the pitch of a musical note will be raised or lowered according to whether the source of the sound is approaching or receding from us. This effect, called the *Doppler* effect, is found in light also. It was noticed that the position of spectral lines produced by light from a moving object is shifted from the position they take when the light-source is standing still. If the source of the light is approaching the observer, the lines are shifted toward the violet end of the spectrum; and if it is receding, the lines are shifted toward the red end. The amount of the shift depends upon the speed at which the light-source is moving. By comparison of a spectrophotograph of a particular star with that of a standard spectrophotograph, not only the relative speed but the direction of the motion of the star can be determined.

By way of summary, let us note that the spectrometer, in conjunction with the telescope and a camera, enables the astronomer to determine the composition of a star, its temperature, speed, and direction of motion relative to the earth.

[1] The method of parallax is used to determine star distances, using the principle employed by surveyors in determining the distances across lakes, etc. If a given star is observed at two intervals, six months apart, so that the observations are made on opposite sides of the earth's orbit, and the angle of the telescope relative to the plane of the earth's orbit is measured, then by trigonometry the distance from the earth to the star can be determined. This method is accurate only for the nearer stars. The angles are so small for more distant stars that results are unreliable for stars more than 300 light-years away.

The Temperature of Stars May Be Measured by Several Other Instruments.

S. B. Nicholson and *Edison Pittit* adapted a simple instrument called the "thermocouple" to the measurement of the temperatures of the different stars. If one of two strips of different metals held in contact with each other is heated, an electric current is produced. The astronomer's thermocouple consists of a minute wire of bismuth and a similar wire of a bismuth alloy containing five per cent tin, joined at their extremities and fastened to a blackened receiver in order to absorb the maximum amount of light from a star. The heat produced by these light rays produces a feeble electric current which is measured with a sensitive current-measuring device called a "galvanometer."

A somewhat similar instrument, the bolometer, was invented by *S. P. Langley*. It consists of two very fine wires of platinum about 1/2500 of an inch in diameter, mounted in a constant-temperature chamber in such a position that light will strike one wire but not the other. The difference in the electrical resistances of the two wires can then be measured with sufficient accuracy to indicate less than 1/1,000,000 degree rise in temperature.

C. G. Abbott has invented the most sensitive heat-measurer known, the kampometer. Its sensitivity exceeds that of the thermocouple or the bolometer, from which it differs in principle. It utilizes the principle that two metals expand unequally when they are heated.

The scientific significance of these different instruments for measuring the temperatures of the stars is that they permit the scientist to check his results by different methods, using different instruments, and thus make his observations more reliable.

The Stellar Interferometer Is Used to Measure the Diameters of Stars.

The stellar interferometer was invented by *Albert A. Michelson* (1852-1931). One such interferometer, used at Mount Wilson, can measure the angle made by a star's disk which is about equal to that filled by the head of an ordinary pin when placed in Boston and observed from New York.

These Instruments Have Given Man a Picture of Our Galaxy.

Number of Stars. *F. G. Pease* (1881-1938) estimated the number of stars in our galaxy to be between thirty and forty billion. Other astronomers have given estimates as low as one billion. There are no estimates today that are considered to be reliable.

Arrangement of the Stars. The stars in our galaxy seem to be arranged in the form of a huge watch, the thickness being variously

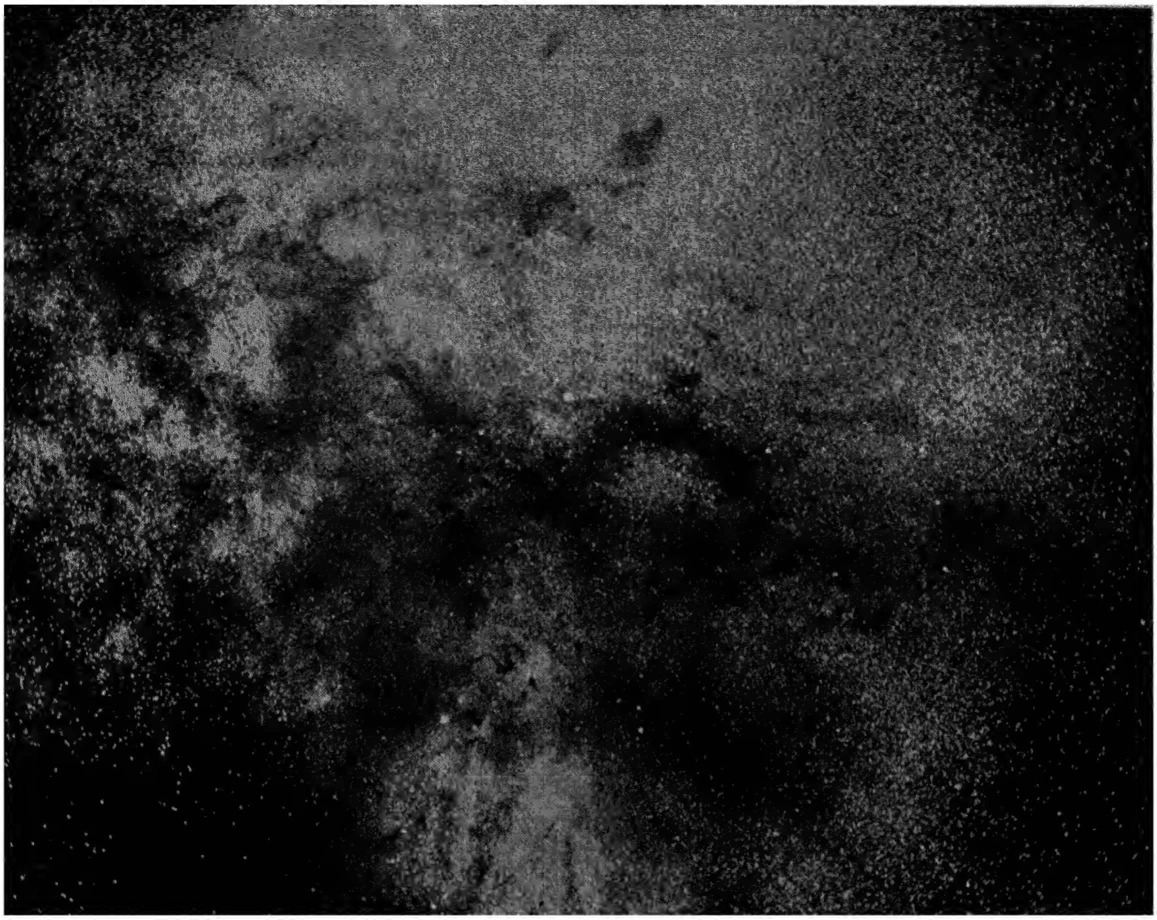


FIG. 7. Milky Way north of Theta Ophiuchi. (Photograph from the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

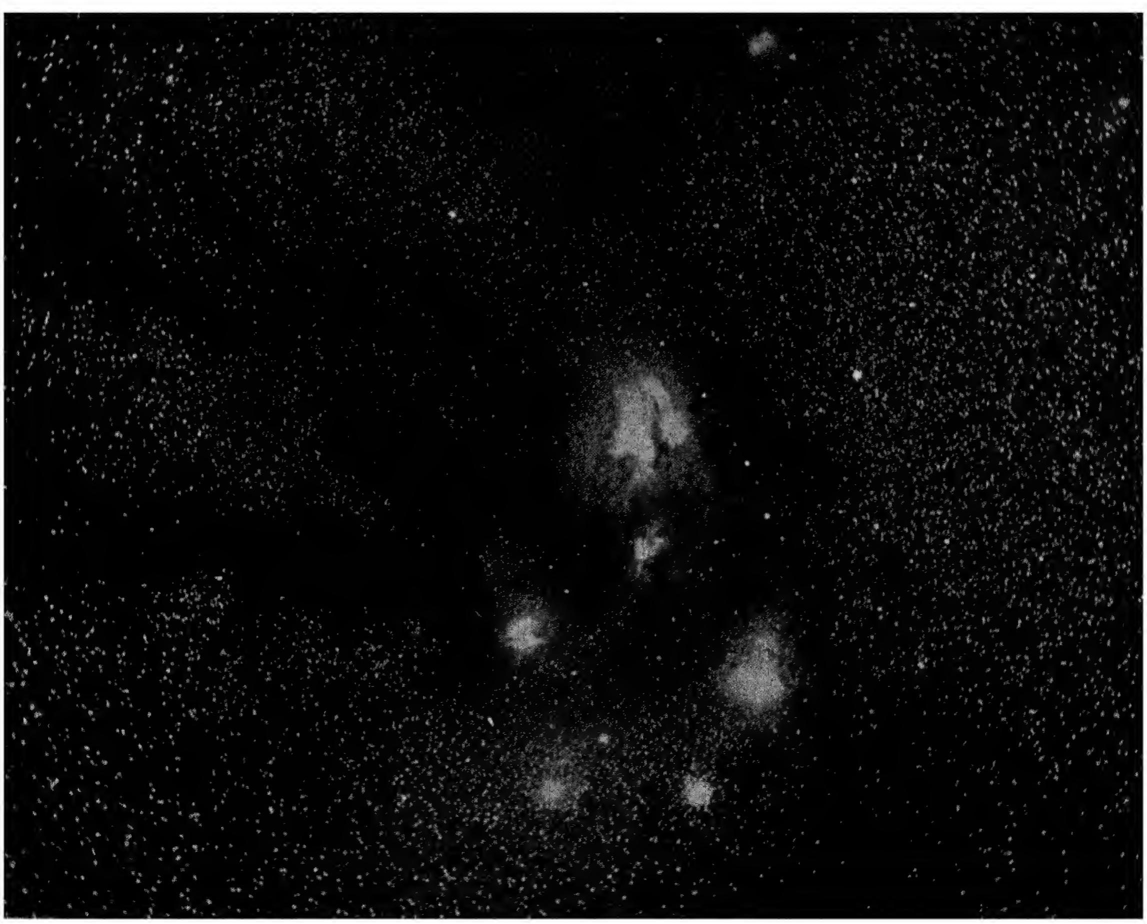


FIG. 8. Milky Way near Rio Ophiuchi. (Photograph from the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

estimated to be from 6000 to 10,000 light-years from face to face, with a diameter of about 100,000 light-years or less. The earth is located inside this watch. When we look at the Milky Way we are looking towards the edge and so see many more stars than when we look toward either face of the watch.

The stars in our galaxy are not evenly distributed. Sometimes they are grouped as star clouds like the star cluster in Hercules, which contains at least 100,000 stars, and probably more. This is only one of several hundred star clusters that appear to be single stars when viewed by the naked eye but are shown to be relatively dense clusters when viewed with the telescope.

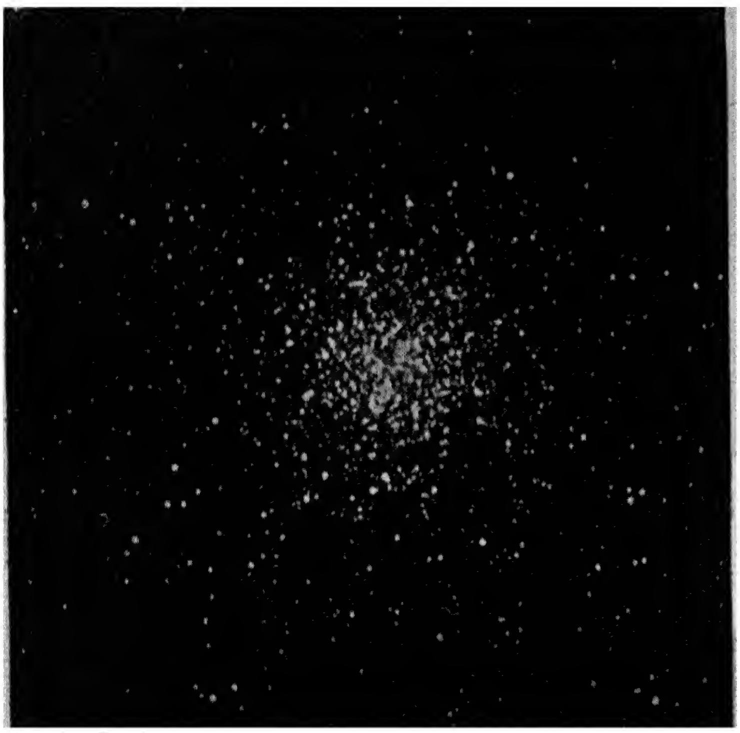


FIG. 9. Great globular cluster in Hercules. (Photograph from the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

Every one of the larger stars shown in the photograph of the great Hercules star cluster radiates at least 1000 times as much light as our sun. The photograph gives the impression that these stars are close together, but appearances are deceiving because this star cluster is so far distant,—between 2000 and 30,000 light-years. Actually the average distance between these suns is about 100,000 times the distance from the earth to the sun. There is plenty of room for each of these suns to have many planets revolving around it, just as our own sun does, although there is no evidence that other stars do or do not have planets.

It would be possible for a single star to pass through a globular star cluster. More than a million years would be required for the passage of a star through such a cluster, and yet these stars are so far apart that it would happen only once in thousands of millions of years that two stars would come close enough to each other to bring about a cosmic collision. Estimates based on the laws of probability indicate that a collision between stars may occur about once every million billion years.

Stars Have Been Grouped as Constellations.

The constellations of the stars have no scientific significance except as an aid in naming and locating stars. The constellations are merely groups of stars that ancient man imagined to fall into definite groups whose formations traced the lines of various objects, in which animals predominated. Thus two bears, several dogs, a lion, a bull, a ram, a horse, a dragon, a couple of serpents, a crab, an eagle, a whale, a swan, and a crow have been named. The Big and Little Dippers are the most familiar figures.

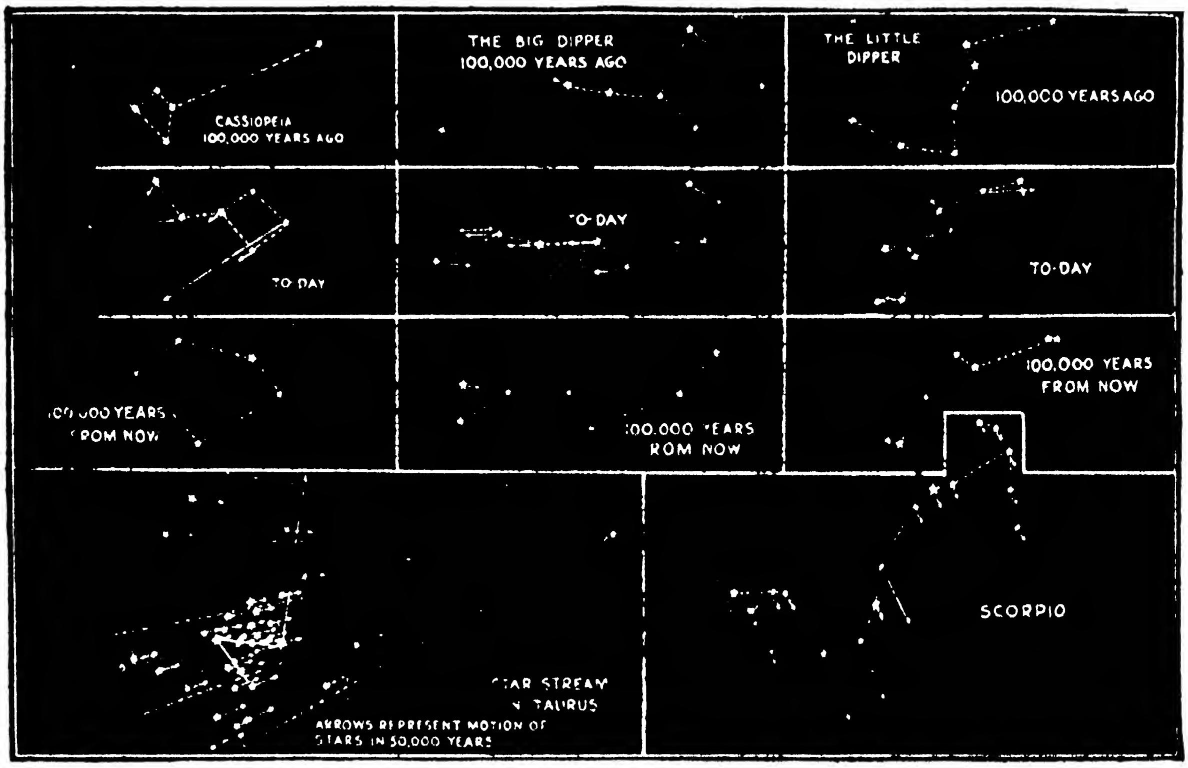


FIG. 10. The changing constellations. The arrows represent the directions in which the stars are moving and the distance which they will travel in the next 50,000 years. Note how the Taurus stream is converging. The effect is one of perspectives. (Drawing by Donald Howard Menzel in *Stars and Planets*, published by The University Society. Reproduced by the courtesy of *Popular Mechanics.*)

Today the brighter stars are usually referred to by name. Thus Vega, Arcturus (made famous by the Century of Progress Fair at Chicago), Betelgeuse, Polaris, Sirius, etc., are well-known stars. Common names would soon run out and would be of no value in locating stars for scientific purposes, so they are named either by Greek letters according to their magnitude in generally accepted constellations, or they are simply numbered according to their position in a given section of the sky.

The accompanying diagram shows how the relative positions of the stars in the various constellations change with time. The constellations do not represent true groups of stars, such as the globular star clusters,

for they are composed of stars too far apart to influence each other's motion appreciably. There are some groups of stars, however, other than the globular star clusters, such as the Pleiades, which move through space as a unit.

Stars Move through Space at Tremendous Velocities. The speed of stars varies considerably, some of them hurrying along with a velocity of 200 miles per second, others at very much less. The average rate is about 18 miles per second. Our own sun is moving toward the constellation Hercules at the leisurely speed of 12 miles per second. So great is the distance of the stars from the earth, however, that any two of the more distant stars moving apart at the rate of 600,000,000 miles per year, characteristic of the speed of many stars, would not show any appreciable change of position within a thousand years.

FIG. 11. The Pleiades and accompanying nebula. (Photograph from the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

Stars Differ in Temperature. The true brightness of a star depends on its size and temperature; a large, cool star may radiate as much light and heat as a small, hot one. The temperature of stars varies greatly. Thus the surface temperature of some stars is only 2500° C., which is 1000° less than the temperature obtained in our best electric furnaces. Other stars have a surface temperature as high as 16,000° C., while the interior temperature of many stars is thought to be as high as 20,000,000° C.

Stars Differ in Size and Density. From the knowledge of the temperatures of stars and other data, it seems to be certain that some stars are merely volumes of very hot gases, so rarefied that they would pass as a good vacuum on earth, while other stars are denser than anything known on earth. Stars do not appear to differ as much as a hundred-

fold in mass, but they may differ in size (volume) as much as a hundred millionfold.

Stars May Pass through a Life Cycle.

Four types of stars are observed:

1. The large, cool, red stars
2. The smaller, bluish-white, very hot stars
3. The still smaller, yellow, hot stars similar to our sun
4. The small, cool, red stars

Some astronomers believe that young stars consist of very large volumes of rarefied gas, barely red hot, similar to Betelgeuse and Antares.

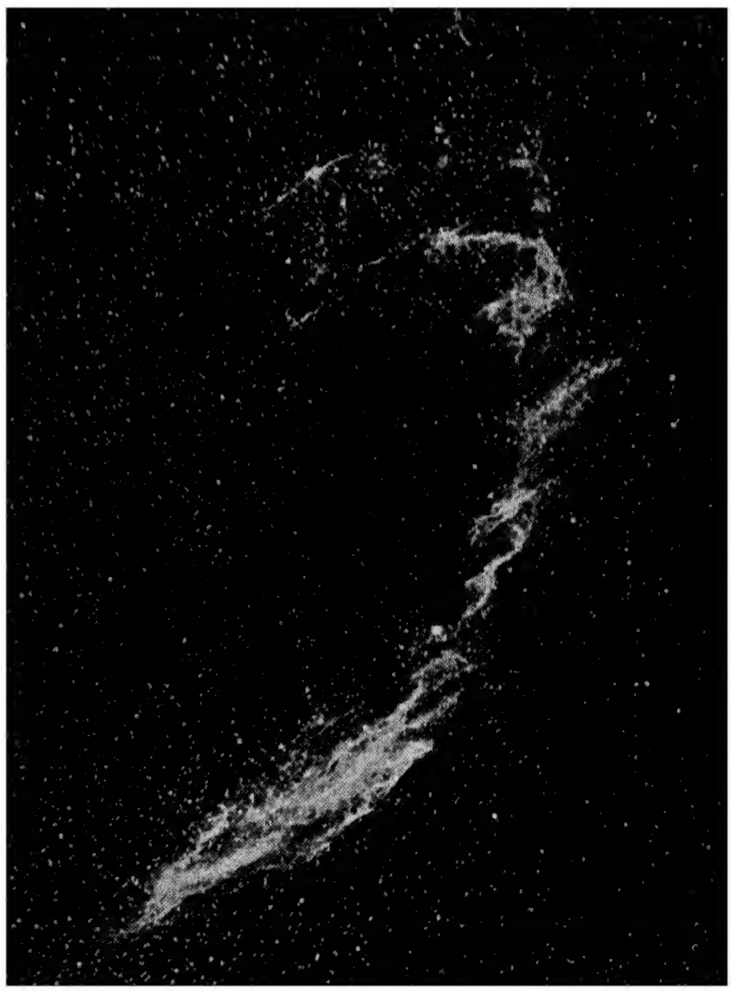


FIG. 12. Filamentous nebulosity in Cygnus. (Photograph from the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

According to one of many theories, these gases gradually condense, the volume of the star becomes less, and the temperature rises tremendously because tremendous amounts of energy (perhaps a thousand times that radiated by our sun) are liberated as the smaller particles unite to form larger, denser ones. After reaching a maximum temperature, the shrinking process continues with a rapid decrease in the liberation of energy, and the star becomes cooler. Eventually it becomes still smaller and cooler until it is a dense, red-hot star. According to this theory, our sun is a middle-aged star about halfway between its maximum and extinction.

Sometimes the small dense stars seem to pass through a second childhood, in which they have a final fling or splurge in the liberation of energy. Such stars are the white-hot dwarfs. Perhaps these stars become so hot that they explode. At any rate, occasionally stars are observed whose brightness increases as much as 100,000 times and are

so bright that they can be seen in the daytime. One of these "novae," as such stars are called, appeared in the constellation of Aquila in 1918, and another one was discovered in Cygnus a couple of years later. This increase of brightness, which can be likened to the sudden change from a small one-cell flashlight to that of a huge searchlight, occurs in a cosmic instant, changing from a very faint light to its maximum. The light gradually decreases to its original intensity in about ten years. Such a rapid change can be accounted for only as an explosion. Additional evidence that explosions really take place is offered by the expanding shells of nebulous matter that have been observed around several novae. About 150 small blue stars have been observed which are surrounded by shells of luminous, nebulous material. These planetary nebulae, as they are called, are thought to be old novae. The cause of these explosions has not yet been found.

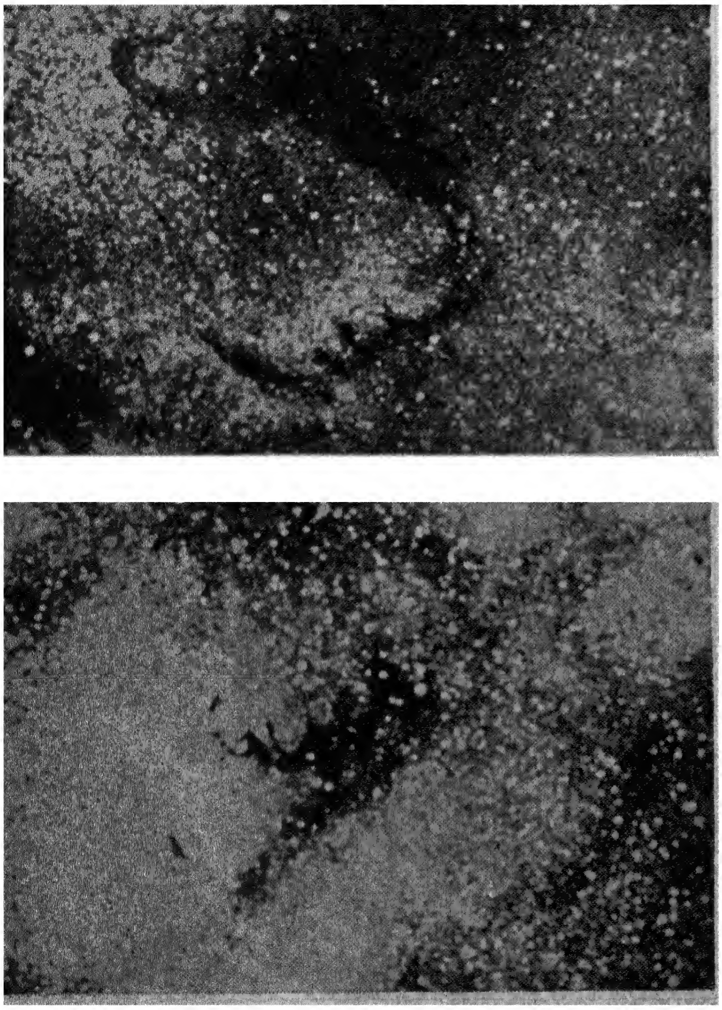


FIG. 13. Dark nebulae in the Milky Way. (Photograph from the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

Our Galaxy Contains Dark and Bright Nebulous Material.

It is thought that the dark splotches formed against a background of stars in the Milky Way do not represent an absence of stars in these regions but rather a blotting out of the light from stars by masses of cosmic dust. (See Fig. 13.) Notice the dark patches in the photograph of the Great Nebula in Orion. (See Fig. 14.) The luminosity of the nebulous material observed in the Pleiades is probably caused by the light reflected from cosmic dust. (See Fig. 11.)

Other nebulae, such as the Great Nebula in Orion, are self-luminous, possibly due to excitation by the energy of nearby stars.

The conception of our galaxy as revealed by modern instruments fills man with awe, but this brief introduction to our galaxy must be

considered as a mere stimulant to the imagination as, in the next Section, we look out into space beyond our lens-shaped galaxy.

FIG. 14. Great Nebula in Orion. (Courtesy Mount Wilson Observatory.)

STUDY QUESTIONS

1. Explain how star distances are determined (1) by methods of parallax and (2) by use of the spectroscope.
2. What are the Fraunhofer lines, and what is their significance?
3. What type of astronomical body is the sun?
4. Name two uses of the spectrometer.
5. What is the Doppler effect?
6. How is the composition of a star determined?
7. How is the intrinsic brightness of a star measured, and why is it needed in measuring star distances?
8. How fast do the stars move?
9. How is the speed of the stars determined?
10. Describe the life cycle of the stars.
11. What is meant by the statement that many stars are multiple?

12. How is the temperature of stars estimated?
13. Why is the camera of great value in studying the stars?
14. What is the scientific significance of the different instruments used for measuring the temperatures of the stars?
15. Compare the variations of stars in density and mass.
16. Are collisions between stars likely to be of frequent occurrence? Discuss.
17. What is the estimated number of stars in our galaxy?
18. What form does our galaxy take?
19. What is the significance of the Milky Way?
20. What is the size of our galaxy?
21. What is thought to be the nature of a nebular cloud?
22. Give one theory to explain the low-temperature periods in the earth's history.

UNIT II

SECTION 4

OUR GALAXY IS BUT ONE OF MANY GALAXIES

Introduction.

In addition to the nebulae that appear within our own galaxy, there are giant star clouds or irregular exterior nebulae,[1] like the Magellanic Clouds, and many spiral nebulae. Our own galaxy is believed to be an unusually extensive nebula about 100,000 light-years, more or less, in diameter. The Great Magellanic Cloud, about 85,000 light-years away, is only about 21,000 light-years in diameter. The great Andromeda Spiral Nebula is about 1,000,000 light-years distant and is estimated to be about 60,000 light-years in diameter. The light from some of these nearest exterior nebulae started on its long journey to the earth about the time when the mammals were developing in the middle Cenozoic period. During the past 6000 years, which have witnessed the tremendous advance of mankind, this light has been traveling through our own galaxy. If every exterior galaxy had been completely wiped out about 1,000,000 years ago, we would not know it today because the light from these galaxies left them before that time.

FIG. 15. The Great Magellanic Star Cloud. (Courtesy of the Lick Observatory.)

[1] Exterior nebulae are nebulae located outside of our galaxy.

Exterior Nebulae Are Found to Be Huge Galaxies of Stars Like Our Own.

Sir John Herschel drew a picture of one of these distant spiral nebulae, Messier 51′, as it appeared to him. Later, in 1845, *Lord Rosse* observed this same nebula with his 72-inch reflector. He found that it

FIG. 16. The Great Spiral Nebula of Andromeda. It is 930,000 light-years distant. (Photograph from the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

was a huge spiral with two long arms extending outward from the central core. It was not long before he discovered thirteen other similar nebulae. It remained for more modern instruments to reveal the true significance of these nebulae. We now know that these exterior nebulae

are systems of stars like our own galaxy, each containing millions of stars.

Edwin Hubble of the Carnegie Institution's Mount Wilson Observatory counted 44,000 nebulae in 1283 photographs covering only a small sample of the sky. On the basis of these figures there would be about 30,000,000 galaxies of stars scattered equally throughout the universe within the distance of 300,000,000 light-years, which is now penetrated by our most powerful telescopes. In 1934 *Harlow Shapley* reported 115,000 new galaxies. He also reported great clusters of galaxies, each consisting of tens of thousands of galaxies, and each measuring 1,000,000,000,000,000,000,000,000 miles across. No wonder that astronomers are anxiously waiting to see what lies out in the unknown beyond.

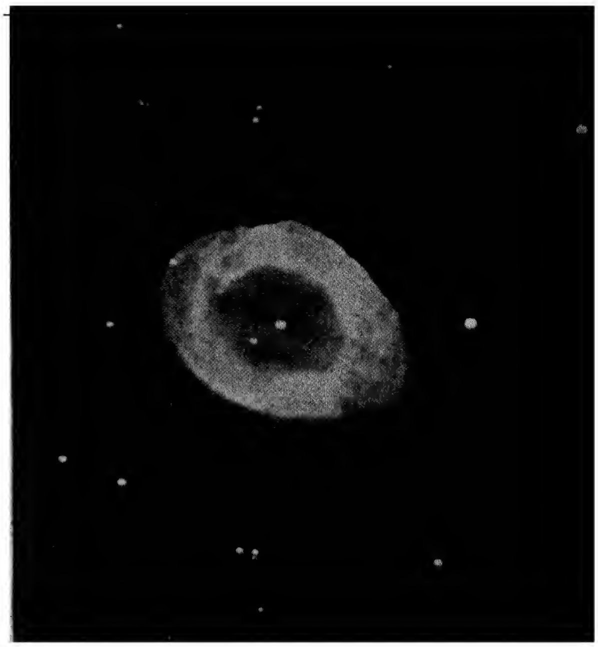


FIG. 17. Ring Nebula in Lyra. (Courtesy of the Mount Wilson Observatory.)

The shapes of these exterior galaxies vary just as the shapes of star clusters and nebulae vary in our own galaxy. Many of them are spiral in shape; others are globular, ellipsoidal, or spindle-shaped; and some are indefinite in shape.

These exterior galaxies are not evenly distributed but are grouped as gigantic supergalaxies. Dr. Harlow Shapley of Harvard considers our own galaxy to be a part of one of these supergalaxies, containing such nearby galaxies as the Magellanic Cloud, the Andromeda Nebula, the Messier galaxy, and five or six other galaxies within a million light-years of each other.

Cepheid Variables Found in Exterior Galaxies Aid in Measuring Their Distance.

Many of the stars in our galaxy, like Mira, vary in brightness. Sometimes Mira is nearly as bright as the North Star, but within a few months it fades until it is forty times too distant to be visible to the naked eye. The increase in brightness occurs with periodic regularity about every 330 days. There are other stars whose brightness varies much less and whose periods are shorter. Our own sun varies in brightness as much as three per cent. The cause of these variations is not known; but *Miss Leavitt* of Harvard Observatory, while studying one

class of these variable stars known as the Cepheid Variables, named after one of the stars in the group, Delta Cephei, discovered that the period of variation is related to the intrinsic brightness. Once the intrinsic brightness of a star is known, its distance can be calculated, of course, by methods already outlined.

It was found that many of the exterior galaxies contain Cepheid Variables which enable us to form our present conclusions concerning the distance of these galaxies from ours. Note that it would no longer add meaning to refer such distances to the earth or the sun.

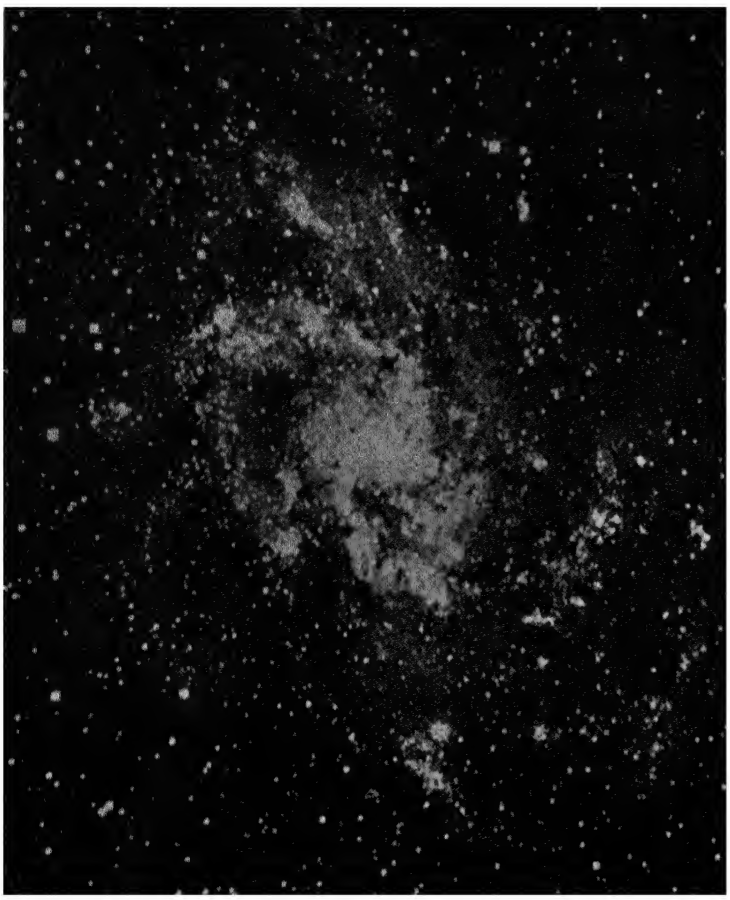


FIG. 18. The Spiral Nebula in Triangulum, Messier 33. (Photograph from the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

Extragalactic Nebulae Move at Various Speeds.

There is a definite rotational motion in spiral nebulae. Photographs taken at ten-year intervals show that the spiral nebula, Andromeda, makes one rotation about every 17,000,000 years.

Some astronomers have suggested that our galaxy, too, is spiral in shape; but little evidence is available. We are too much a part of it to see it in the proper perspective. There is evidence, however, that our galaxy rotates once in about every 100,000,000,000 years.

The exterior galaxies are the "speed demons" of the universe; at least the shift in the Fraunhofer lines indicates that Andromeda is approaching our galaxy at a speed of nearly 200 miles per second. All of these galaxies seem to be moving in the same general direction, perhaps as a single organization of supergalaxies, which Shapley would call a metagalaxy.

The fact that all of the galaxies seem to be receding from one another has led to the theory of an expanding universe.

It is well at this point to emphasize the fact that our present ideas concerning the nature of the universe are founded on scientific observations but that they are subject to a considerable change due to the meagerness of our information and judgment.

In the next Section we shall return to our own little Solar System. Do not think for a moment, however, that nothing more remains to challenge the imagination. For as we turn to the study of smaller things — the sun, the earth, ourselves, down to microscopic objects — and still others out beyond the range of the microscopic objects — we again become confronted with the unknown. But now let us hasten on to the study of the vast known that lies between these realms, for our penetration of the unknown is all based on this firm foundation.

How Important Is Man in This Vast Scheme of Things?

Man now wonders what his position in the universe is. It is true that the modern revelations of the universe have administered a rude shock to man's conception of his relative importance; but on the other hand, he gains respect for himself as he comes to realize what knowledge his intellect has made possible. It is well to keep in mind that although, astronomically speaking, man is very small, still astronomically speaking, he is the *astronomer*.

STUDY QUESTIONS

1. What is the nature of the extragalactic nebulae according to modern theories?
2. How many extragalactic nebulae are there?
3. What forms do extragalactic nebulae take?
4. What is the distance of the Andromeda Spiral from the earth?
5. Discuss the motion of extragalactic nebulae.
6. How has the picture of the universe, as revealed by modern astronomy, changed your thoughts concerning yourself and your importance in the vast cosmic scheme?

UNIT II

SECTION 5

THE EARTH RECEIVES MOST OF ITS ENERGY FROM THE SUN

Introduction.

If man wanted to find some object in the universe to worship, the sun would probably be selected, because it is the source of our light and heat, and because our food, clothing, and housing could never have been formed without its valuable rays.

Perhaps it would be better to select some other star, for as stars go, the sun is only middle-class. However, although there are much larger stars a thousand times brighter, this particular star would still be selected because it is our star.

The Sun Is a Giant Sphere of Hot Gas.

The sun is a giant sphere of glowing gas, more than one million times the volume of the earth. Its diameter is about 864,000 miles. The average distance from the sun to the earth is 93,000,000 miles.

The temperature at the surface is about 6000° C., while it is estimated to be 22,000,000° C. at the center. Experiments with high temperatures indicate that every terrestrial substance thus far examined would be in the form of a vapor at the temperature of the interior of the sun. This conclusion is confirmed by the solar spectra, which show at least 64 of the 92 known or suspected elements to be present in vapor form in the sun. It is probable that the other elements are present in too small proportions to give spectroscopic evidence.

The heavier gases of the sun are surrounded by a layer of light, hot gases and vapors about 5000 to 10,000 miles in depth, which is called the chromosphere. Outside of the chromosphere is the corona, seen only during eclipses, which consists of hot, highly rarefied gases that extend from the chromosphere a distance nearly equal to that of the sun's diameter. One theory accounts for the corona by assuming that the pressure of the sun's radiation pushes the gases out into the space surrounding the sun. From this fiery layer great lurid tongues of incandescent hydrogen shoot out, sometimes to a distance of 500,000

miles. One such prominence, as these tongues are called, was observed to shoot out of the chromosphere at the rate of 60,000 miles per hour.

Although the volume of the sun is more than a million times that of the earth, its relative mass is much less, because the density [1] of the earth is about four times that of the sun.

Sunspots Are the Cooler Portions of the Sun's Surface.

The surface of the sun is mottled with dark spots, ranging from 500 to 150,000 miles in diameter. These sunspots represent relatively cool areas, whose temperature is about 4000° C. as compared with the 6000° C. which is the temperature of the hottest outer portions.

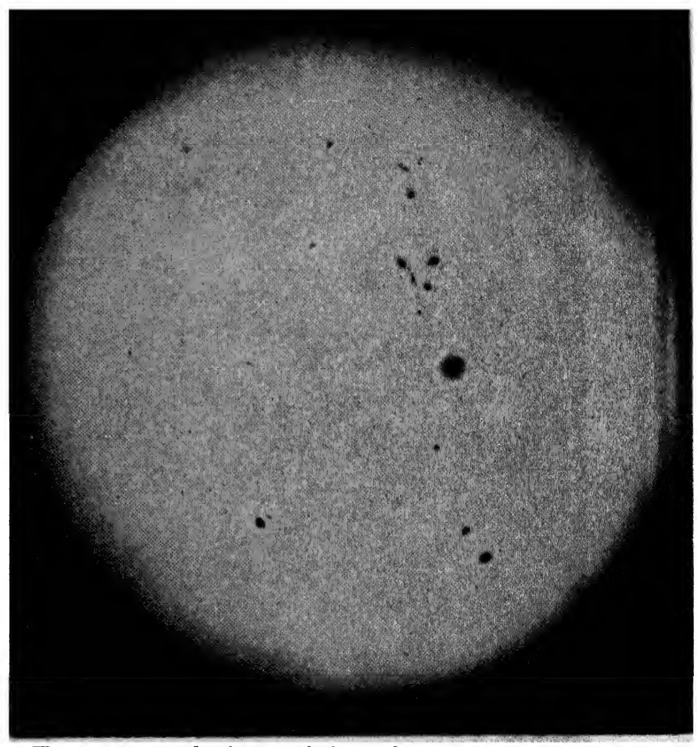


FIG. 19. Solar disk with many spots of unusual size, November 30, 1929. (Photograph from the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

It is thought that the sunspots are areas of lowered temperature resulting from tremendous solar cyclones, which increase to a maximum and then for some unknown reason decrease periodically every eleven years. Studies of annual tree rings show that they vary in a similar eleven-year cycle. When these solar disturbances are at their maximum, magnetic disturbances occur on the earth that interfere seriously with telegraphic, telephonic, and radio communication. The aurorae are also more brilliant at such times. These disturbances on the earth may be due to increased streams of electrons and ions or greater ultraviolet radiations coming from the sun, as a result of changing solar conditions.

George E. Hale proved that sunspots behave like huge magnets. The direction of the whirl of the sunspots in each succeeding cycle is reversed, thus reversing the magnetic fields.

A great magnetic storm occurred in April, 1938, in which energy was expended at the rate of two billion kilowatts for a two-hour interval,

[1] Density is the mass of a unit volume of a substance. For the present you may consider that mass means about what is commonly meant by weight. A more exact usage of these terms will be given later. Density may therefore be considered to be weight of a unit volume.

according to *A. G. McNish* of the Carnegie Institution. This storm was accompanied by obstruction of transatlantic radio communication, numerous interruptions in wired communications services, and interference with the operation of electric power systems.

There is some evidence that the weather is influenced by sunspots. *W. B. Schotakovitch*, after studying the records from 1869 to 1920, concluded that sunspots bring more rain on the average over the whole

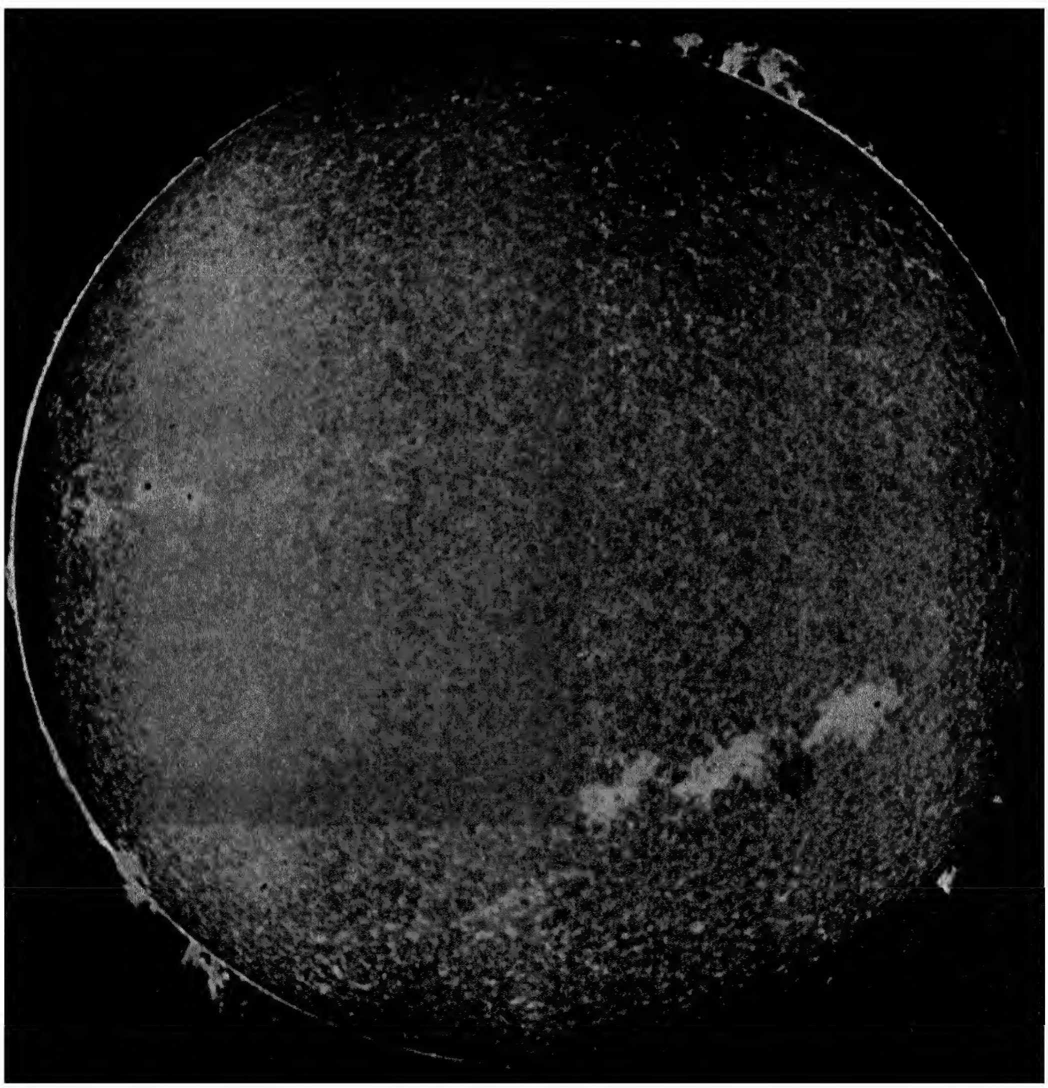


FIG. 20. The sun, showing unusual activity in both flocculi and prominences. (Photograph from the Yerkes Observatory, reprinted by permission of the University of Chicago Press).

earth, because the earth receives more radiations during a sunspot period, and this increased radiation produces more heat, which evaporates more water, which precipitates as rain.

The sun rotates about its axis in the same direction as does the earth; but not being a solid, it does not rotate uniformly as a whole. Thus spots on the sun's equator rotate in about 24.6 days as compared with a rotational period of 34 days or more near the poles.

The Source of the Sun's Energy Is Still Unknown.

The amount of energy that finally reaches the earth is very large. Measured by the pyrheliometer, it is found that the earth receives 230,000,000,000,000 horsepower, continuously, or about 160,000 horsepower for every human being. The amount of energy radiated by the sun would be sufficient to melt a 40-foot shell of ice around the sun within one minute. The generators at Boulder Dam will be able to generate 663,000 horsepower, which means that it will be able to harness about 1/340,000,000 of the sun's energy which reaches the earth.

When we consider that the earth and its atmosphere intercept only about one two-billionth of the total energy emitted by the sun, and when we consider how much energy this two-billionth represents, we wonder whether the sun is not gradually growing cooler as it loses all of this energy.

Indelible records preserved in the rock layers of the earth indicate that there has been no noticeable permanent change in the amount of energy that the earth has received during the past billion years. This observation indicates either that there is so much energy in the sun that the relative amount lost in a billion years is negligible or that there are changes taking place within the sun which liberate energy.

Hermann Helmholtz (1821–1894), a German physicist, suggested that energy was evolved by a gradual condensation process within the sun, but later calculations showed that such a process would account for less than one hundred-thousandth of the energy it has already lost.

Astronomers agree that the sun would show a decrease in temperature after a period much shorter than a billion years if the energy lost by the sun was not renewed continuously.

Sir Isaac Newton suggested that matter itself might be changed into radiations, but it remained for recent studies of radioactivity and nuclear chemistry to provide some concrete evidence which places such an idea within the range of possibility.

It is now supposed that this energy is liberated either by constructive or disintegrative processes taking place within the sun which change matter into energy.

Radioactivity gives off a great deal of heat and produces helium as a by-product. The fact that there is considerable helium in the sun was responsible for the radioactive-decomposition theory of the source of the sun's energy. More recently, however, a reaction in which matter is built up rather than decomposed has been found to fit all of the known facts.

A recent hypothesis, advanced by *Bethe*, that seems reasonable is

that the sun's energy is liberated in a series of reactions between hydrogen and carbon in which the carbon is regenerated but the hydrogen is converted into helium. The rate of this reaction corresponds closely with the actual rate of radiation observed for the sun. Eventually, however, the sun seems doomed; and as it becomes colder, life on earth must cease to exist.

Perhaps, in the future, man may discover the sun's secret and be able to produce energy by subatomic changes. For the present, however, man finds that the problems of harnessing and controlling the energy of the sun present more likely prospects.

At present man utilizes the sun's energy after it has been converted into the potential energy of water stored above sea level, or into the kinetic energy of the winds, or into the chemical energy stored up in the forms of food, wood, coal, gas, and oil.

A few small solar heaters and engines have been devised, by which the sun's energy is transformed directly into heat, but practical developments along this line are not yet in sight.

STUDY QUESTIONS

1. How long does it take for light to travel from the sun to the earth?
2. How far is the sun from the earth?
3. Is the sun gaseous, liquid, or solid? Give reasons for your answer.
4. Discuss the temperature of the sun.
5. Compare the sun and the earth as to density.
6. To what extent does the earth's atmosphere diminish the amount of heat received by the earth from the sun?
7. Give some data to show how much energy is received from the sun by the earth.
8. What is a possible source of the sun's energy?
9. What is thought to be the nature of the sunspots?
10. How do the sunspots influence the earth?
11. What are the indirect ways of using the sun's energy?
12. How would you construct a solar heater?

UNIT II

SECTION 6

NEWTON'S LAWS ARE UNIVERSAL IN THEIR APPLICATION

Introduction.

It will be recalled that Kepler stated his observations of the motions of the planets in the form of three laws; but it remained for one of the greatest scientists the world has ever produced, *Sir Isaac Newton*, to state the universal laws of motion which apply to all objects, small or large.

Newton's Law of Universal Gravitation Is Useful in Describing and Predicting the Motion of Planets.

Isaac Newton's (1642–1727) law of universal gravitation is most simply stated as follows: *Every body of matter in the universe attracts every other body along the straight line that joins them, with a force proportional to the product of their masses and inversely proportional to the square of the distance between their centers.*

The important idea that occurred to Newton was not that objects are attracted to the earth — this fact was common knowledge — but that every object in the universe exercises an attraction for every other object in the universe.

In developing his law of universal gravitation, Newton set out to see whether or not the motion of the moon corresponded with his predictions which were based on the law. He met with difficulties at once because different parts of the earth and the moon were not equally distant from the center of each. Newton finally solved this problem by using a new kind of mathematics, calculus, which he had to invent for the purpose. Calculus has been of inestimable value to modern science in solving a wide variety of problems.

The Companion of Sirius.

Sirius, the "dog star," is the brightest star in northern latitudes visible above the southern horizon in winter months. It is only 8.6 light-years distant. For many years it was used as a clock star as a standard for time, but it was found unsatisfactory because of its shifting position.

Sirius was found to shift back and forth every 25 years. In 1844 *Bessel*, on the basis of his computations of the orbit of Sirius, predicted that Sirius was a double star. Later both Sirius and its companion were observed through a telescope.

The companion of Sirius is a very interesting star, for although its mass is 4/5 as great as that of the sun, it radiates only 1/360 as much light. It must, therefore, either be cooler or have a much smaller surface than the sun. When it was proved in 1914 that the companion of Sirius is a white-hot star, the conclusion was drawn that it must have a smaller surface. The volume of the companion of Sirius is estimated to be 0.00004 of the volume of the sun. Its diameter is about 1/19 of the sun's diameter, which would make it about the size of the planet Uranus, or three times the size of the earth. Inasmuch as the companion of Sirius is therefore at least 40,000 times as dense as water, a pint of its mass would weigh 20 tons, and a tablespoonful could not be lifted by a strong man.

It seems unbelievable that matter in the gaseous state could exhibit such a high density, but such is our confidence in Newton's laws upon which our calculations are based that we must abandon "everyday common sense" for the higher common sense of Science. Accurate checks of Sirius' mass, size, and temperature leave no other conclusion. A number of other white dwarfs (stars resembling the companion of Sirius) are known. One of these white dwarfs has twice the mass of the sun, and yet it is no larger than the planet Mars. The gravitational attraction of this star would be so great that it would cause a man to spread out on the surface like a puddle of water. A cubic inch of matter from the white dwarf star, Wolf 457, would weigh 9000 tons, *i.e.*, just under the weight of a navy cruiser; and if it were placed in a modern skyscraper, it would probably crush its way right through the building and proceed toward the center of the earth as a cannon ball sinks in water.

Dwarf stars are now considered to be made up of the nuclei of atoms, which represent most of the mass of atoms but occupy a very small portion of the space taken up by an entire atom. Another theory is that these dwarf stars are made up of very heavy elements not known on the earth.

Betelgeuse Exhibits Conditions at the Other Extreme.

Betelgeuse is a bright star in the shoulder of Orion, 192 light-years from the sun. This giant red star has a diameter 345 times that of the sun, or about 300,000,000 miles, and its volume is 40,000,000 times that of the sun's volume. Inasmuch as its mass is only twelve times

that of the sun, it must have a density of only 1/1,000,000 that of water, or 1/1000 that of air.

The Tides Are Produced by the Gravitational Attraction of the Moon and the Sun.

Tides are caused by the gravitational attraction of the moon and the sun. The moon is the principal cause of the tides. The sun's tide-raising force is only about 2/5 that of the moon inasmuch as the sun is 400 times as far from the earth as is the moon and inasmuch as the

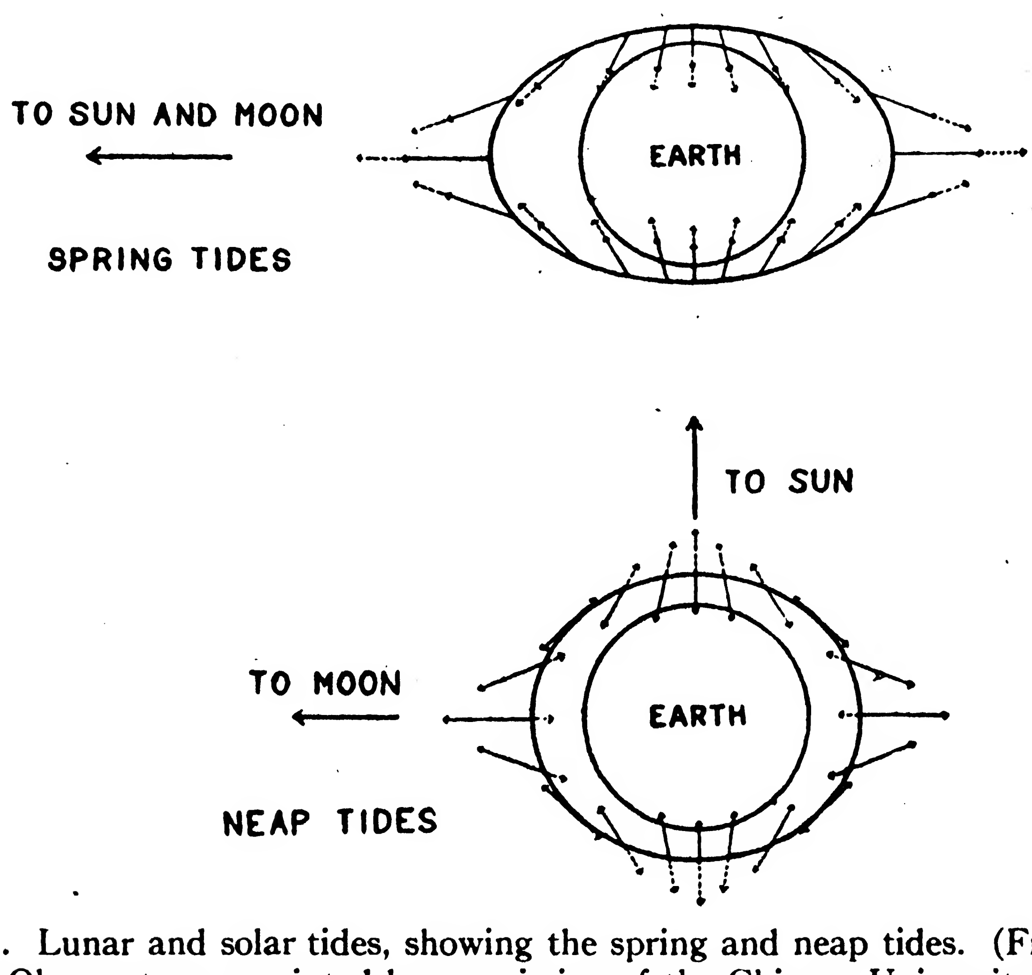


FIG. 21. Lunar and solar tides, showing the spring and neap tides. (From the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

attraction varies inversely as the square of the distance and only directly as the masses. Twice each lunar day (24 hours, 52 minutes) this attraction acts to increase the depth of the water in the oceans at different times in different localities. The fact that the tides are synchronized with the lunar day rather than with the solar day proves that the moon is chiefly responsible for the tides.

The waters on the side of the earth nearest the moon are drawn toward it, while those on the other side are attracted least of all and tend to rise because the earth is attracted more than the water. Thus high tides occur on the sides next to and opposite the moon, while low tides are found at positions just midway between these points.

The "spring" [1] tides are the highest because they occur when the pull of the sun and moon are acting together, in other words, when the sun and moon are on the same or opposite sides of the earth.

The "neap" tides occur when the gravitational pull of the sun exerts the maximum neutralizing effect on the gravitational pull of the moon. The physiographic features of the earth's surface modify the intensity of the tides, delaying their arrival at different points.

Because of the presence of the continents, the tides in the Atlantic, Pacific, and Indian oceans are secondary tides produced by the primary tides in the Southern ocean.

The height of the tides varies from one foot to forty feet.

Weight and Mass Are Proportional to, but Not Identical with, Each Other.

It was pointed out at the beginning of this Section that all bodies in the universe attract each other with a force that is called gravitation. A special but very familiar example of this force is the force exerted on objects at the earth's surface. This is called their weight. This force, like every gravitational force, is proportional to the mass of the body, as stated in the expression of the general law of gravitation. It is also proportional to the mass of the earth and inversely proportional to the square of the earth's radius, but these quantities do not vary much. It is true that a body weighs slightly less on a mountain top than it does at sea level, because there is a greater distance between the centers of gravity. But the force of gravity at the surface of the moon is only one-sixth of that for the same body at the earth's surface because the moon is so much lighter than the earth. On the moon, then, the weight of a body will be one-sixth of its weight on the earth.

It is obvious, however, that there is something about an object that does not change, though its weight does. This unchanging property of matter is its mass, as already referred to in connection with the general law of gravitation. It is properly measured by the reaction of the body when it is acted on by a force, as will be discussed below in connection with Newton's second law of motion. In practice, the masses of two bodies are compared by their weights, to which they are proportional. The bodies are placed on the two pans of a balance, such as the chemist uses, and adjusted until the weights are equal. Then, by Newton's general law of gravitation, the masses are also equal. Balances are thus a device for comparing masses. Many food markets

[1] "Spring" is a name in this case which has no relation to the spring season of the year.

use spring scales, in which the weight is balanced by the pull of a spring, whose elongation gives a measure of the force it exerts. If they were transported to the surface of the moon, the balances would still indicate a balance, for the masses are unchanged. The spring scale, however, would read only one-sixth as much, for the weight would be decreased in that proportion.

Einstein Has Shown That Newton's Law of Gravitation Applies Rigorously Only to Matter at Rest.

Newton's law of gravitation holds for matter at rest but is slightly inaccurate for matter in motion.

Einstein's theory of relativity holds that mass increases as matter travels faster and that at the speed of light it would be infinitely great. Experiments with very small particles moving at great velocities show that Einstein is right — that they do increase in mass as they increase in speed.

Einstein's theory of relativity considers time to be a fourth dimension of the calculation concerning time and space; the entire space-time system is considered to be curved into a spherical shape caused by the fairly equal distribution of the masses in the universe. There are no ways of testing many of the revolutionary ideas presented in Einstein's theory, but some of the conclusions based upon this theory have been tested and confirmed. For example, Einstein predicted that the mass of the sun would curve the space near the sun to such an extent that light passing through this space near the sun's surface would deviate from its normal path by 1.75 seconds of an arc.

The British Royal Astronomical Society sent out two expeditions — one to Sobral in Brazil and the other to Principe in West Africa — to make observations of the eclipse of the sun on May 29, 1919. Photographs of positions of the stars appearing close to the edge of the sun were made, and the discrepancies observed in the positions of these stars were found to be in good agreement with Einstein's predictions. Later, in 1922, the Lick Observatory found the deviation to be 1.72 seconds, as compared with Einstein's predicted deviation of 1.75 seconds.

Because of its speed, the path of light is curved only slightly, but the paths of less rapidly moving bodies would be curved to the extent that they would travel around the sun in hyperbolic, parabolic, or elliptical orbits, depending, respectively, upon their speeds. The paths of certain rapidly moving comets are nearly in agreement with Einstein's ideas. This theory has also explained some otherwise puzzling details in the motion of the inmost planet, Mercury.

Newton's Laws of Motion Form the Foundation of Mechanics.

It is a common observation that:

1. *A body at rest remains at rest, and a body in motion moves at a uniform velocity in a straight line, unless the body is acted upon by some external force to change its state of rest or motion.*

This statement is Newton's first law of motion. This property of matter to remain motionless or in uniform motion, unless acted on by some outside force, is called inertia. It is possessed by all bodies in some degree but cannot be defined more explicitly. The quantity that is used as a measure of inertia is the mass of the body, which has already been referred to in connection with the law of gravitation. This mass enters into the second law; but before we can express the law, we must also understand what is meant by velocity.

The velocity with which an object moves is the distance it travels in a given direction divided by the time it takes to travel that distance. It is expressed as the distance covered per unit time.

The second law tells what happens when a force changes the velocity of a body. It may be expressed thus:

2. *The change in velocity of a body, multiplied by the mass of the body, is proportional to the force and the time for which it acts and is in the direction of the applied force.*

This law may also be expressed in terms of the *acceleration of the body*, which is *the rate of change in the velocity of a moving object.* This change is caused by a force, and the product of the mass of the object by the acceleration is proportional to the force applied. Thus a heavy truck, with its greater mass, will have a smaller acceleration, or pickup, than an automobile when acted on by a given force. The accelerator in the automobile controls the force that acts to change the velocity of the automobile and accelerate it.

Modern automobiles have a quicker "pickup" than older automobiles because their motors are more powerful and because they are constructed from light alloys of great strength to reduce their inertia. An automobile engine capable of producing a speed of 100 miles per hour was not constructed for that purpose but rather to provide greater "pickup" and greater power on hills.

Greater power is required to go up hills because a force equal to the force due to gravity has to be exerted in addition to that required for forward motion.

A stone thrown into a lake, in a direction horizontal to the lake, from a bank ten feet high would strike the water at the same time that another stone would strike the surface if merely dropped from a point at the same distance above the lake. The gravitational force is not

changed by the motion in a horizontal direction so that both forces acting at once determine the path of the stone.

It is possible to calculate just what angle to set a gun so as to cause a given projectile to fall at a predetermined position. It can be understood that great skill is required to hit an airplane traveling two hundred miles per hour, with a shell from an anti-aircraft gun, because such hits are the result of careful calculations, which must include many factors and which must be made with little loss of time.

Newton's third law of motion simply states that:

3. *To every force or action there is an equal and opposite reaction,* which is exerted on the body that exerts the action. The kickback of a gun or a cannon is an illustration of this law. Another good example is encountered when you stand on a freely rotating platform and turn your head to the right; you will find that your body turns to the left. If you wave a weight in a circular fashion above your head, your body will rotate in the opposite direction so as to maintain a zero resultant momentum. Now suppose that someone starts you spinning around, and thus you acquire a given momentum. (Momentum is proportional to the product of the mass times the speed.) If you hold out your hands you will move more slowly because you are causing a portion of your mass to travel through a greater distance.

Another illustration of Newton's third law of motion can be carried out by the use of a spinning gyroscope. (A bicycle wheel, whose tire has been replaced by many windings of heavy wire and mounted on an axle which may be held in the hands, will serve the purpose.) If you stand at rest on the table and hold the axle of the spinning gyroscope horizontal, it does not affect your position. But, if you turn the axle of the spinning wheel toward the vertical position, you will find that your body is spun clockwise or counterclockwise, depending upon the direction in which the axle is tilted. The reason that you turn is that you have imparted an angular momentum to the gyroscope, which must be balanced by an opposite and equal angular momentum of your body.

The principle of the gyroscope is a little difficult to understand. The gyroscope is brought into this discussion solely because the earth, too, is a spinning body and therefore exhibits the characteristic behavior of the gyroscope.

If a large gyroscope is mounted on a vertical axis which is free to turn about a horizontal axis and is kept spinning by an electric motor, it will act as a stabilizer for monorail trains, airplanes, and ships. As the ship rolls, it tips the axis of the gyroscope along with the rest of the ship and thus tends to cause precession; but inasmuch as the gyroscope is so

mounted that precession is prevented, the whole ship is moved by the gyroscope in such a way that the rolling is reduced.

The gyrocompass is a useful modern invention that is free from the defects of the magnetic compass, which is particularly troublesome on iron vessels because of the large amount of steel they carry. The rotation of the earth causes precession of the gyroscope, and its axis therefore always points to the true geographic North Pole rather than to the magnetic north pole.

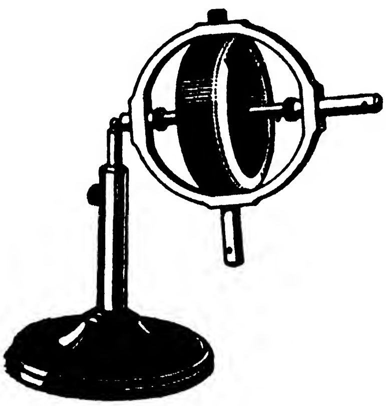


FIG. 22. A small gyroscope supported at one end so as to show precession.

Precession can be observed in the experiment in which a toy gyroscope top, when placed with one end on a support, will rotate around the support rather than fall as long as the gyroscope is spinning fast enough.

Because the earth is not perfectly round, the pull of other bodies is unequal, and the earth shows a precession that is due four-fifths to the moon and one-fifth to the sun. The result is that the axis of the earth changes direction so that it would trace a large circle in the heavens in about 26,000 years.

The calculations required to determine the amount of this precession of the earth are based upon the size of the earth, its density, the distribution of mass upon it, the laws of motion, the rate of rotation of the earth, its oblate shape, the distances to the moon and sun, their apparent motions with respect to the earth, and the law of gravity. The fact that actual observations are in harmony with the calculated theoretical results serves to add still more to our ever increasing confidence in Newton's laws.

Newton's Laws Apply to the Motion of the Heavenly Bodies.

Newton's laws of motion were expressed originally to explain Kepler's laws of the motion of the planets, as given on p. 58. Kepler's second law about the equal areas is simply an application of the principle of the conservation of angular momentum, which has been discussed in connection with Newton's third law of motion. But how do the laws account for the elliptical paths of the planets?

According to the first law, the planets would move in straight lines unless acted on by some force. This force is the gravitational force between the sun and the planets which constantly attracts the planet toward the sun by changing the direction of the planet's motion. This force, which attracts the planet to the sun and just balances its *centrifugal* force, the result of its tendency to move in a straight line,

is called the *centripetal* (*i.e.*, center-seeking) force, and the acceleration it causes is the centripetal acceleration.

Thus the planets are continually falling toward the sun but are at the same time swinging past it, so that they never reach the sun. It is like the motion of a bomb dropped from a rapidly moving airplane directly above a target. It is attracted toward the target but will not hit it, because its forward motion will carry it far past it. If it were going fast enough, it could go on swinging indefinitely around the center of attraction; and this is exactly what the moon does. Newton calculated how great the ("falling") centripetal acceleration of the moon would be according to the inverse-square law of gravitational force. He was led to the inverse-square law by Kepler's first law of planetary motion, for he calculated that an elliptical orbit with the sun at one focus would require a force that varied in that manner. He also found that the same gravitational force would explain the falling of the moon and the apple in the orchard. Then he went boldly ahead and assumed that a similar gravitational force would exist between any two particles of matter in the universe.

If we apply Newton's third law of action and reaction to the gravitational centripetal force, we find that there is an equal force of attraction acting on the sun. Why does this not cause an acceleration of the sun? The answer is that it does, but the sun has a so much greater mass than any of the planets that its motion is negligible compared to that of the planets. The reaction to the centripetal force is of course in the opposite direction, namely, away from the center, and is commonly called the centrifugal force. It does not, of course, act on the body that moves in a curved path, such as a planet, but on the thing that makes its path curved. A familiar example of this is the tug of the string on the hand when a stone on the end of the string is whirled in a circle. The forces on the stone are not balanced; the stone is accelerated toward the hand. If the string is let go, the stone will cease to follow its former path. So also an automobile goes off the road on a curve when the centripetal force becomes too small to cause the required acceleration, either because of too great a velocity or because of a decrease of the centripetal force by decreased friction ("grip") of the tires, as when the road is coated with water, wet leaves, snow, or ice.

The centrifugal action of a body is its tendency, as expressed by its inertia in Newton's first law, to continue moving in a straight line. This centrifugal tendency is applied in numerous devices. It is responsible for the water flying off the grindstone. It is used in the centrifugal air pump of the vacuum cleaner. Some washing machines remove excess water from wet clothes by centrifugal spin driers.

Similar equipment is used in sugar refineries and many other industries to remove crystals from the liquids in which they are formed. The Babcock milk-tester and cream-separator separates the cream from the denser portions of the milk because the denser portions, with greater inertia, have a greater centrifugal tendency and resistance to centripetal acceleration. This tendency is also applied in centrifugal water pumps, the governors of engines, and the cowboy's lariat.

And finally, it is this same centrifugal resistance to centripetal acceleration that causes the earth to bulge at the equator.

STUDY QUESTIONS

1. State Newton's laws of motion and illustrate each by a concrete example not given in the text.
2. Upon what two things does the measure of attraction between two bodies depend?
3. State Newton's law of universal gravitation.
4. Give evidence that Newton's laws of motion are invariable.
5. Differentiate between mass and weight.
6. Why does the earth not travel in a straight line through space relative to the position of the sun?
7. Give an illustration of an application of centrifugal force in the home.
8. Give five illustrations of the application of centrifugal force.
9. What is centrifugal force?
10. What keeps the earth in its orbit?
11. Would a planet of large mass have to move more or less rapidly than a planet of smaller mass to enable its centrifugal force to balance the force of attraction of the sun?
12. Pluto is a small planet like the earth, but it is much farther from the sun than the earth. Does it move more or less rapidly than the earth?
13. Why is it advisable to slow down on turns?
14. Why is it thought that the companion of Sirius is composed of very dense matter?
15. State and illustrate Newton's first law of motion, *i.e.*, the law of inertia.
16. State and illustrate Newton's second law of motion, *i.e.*, the law of force.
17. State and illustrate Newton's third law of motion, *i.e.*, the law of action and reaction.
18. What is weight, and how is it measured?
19. What is mass, and how is it measured?
20. What is force, and how is it measured?
21. Use the terms force, velocity, and acceleration in describing the motion of an automobile.
22. Explain the tides.
23. Explain the precession of the earth.
24. Describe an experiment which seems to confirm Einstein's suggestion that space is curved.

UNIT II

SECTION 7

THE EARTH IS BUT ONE OF THE SUN'S PLANETS WHOSE MOTION FOLLOWS UNIVERSAL LAWS

Introduction.

Around the sun revolve bodies or planets of varying size. The earth is but one of these planets. Some of them revolve in orbits relatively close to the sun, while others are so far distant that their existence was never even suspected by astronomers until recent times. The ancient Babylonians, Egyptians, and Greeks recognized five "wanderers"

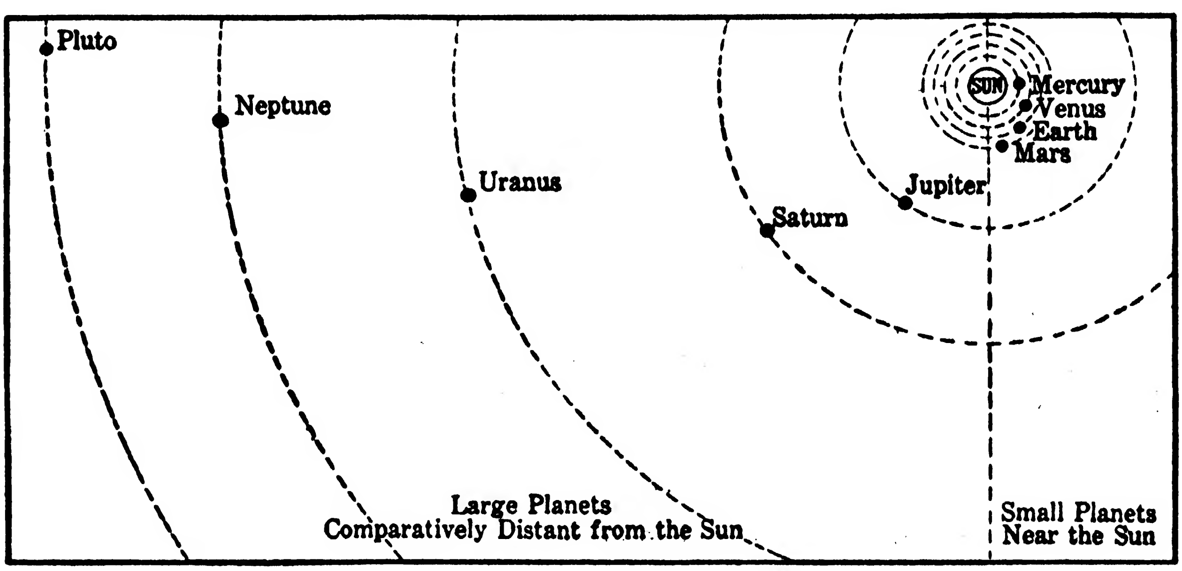


FIG. 23. The relative distances of the planets from the sun.

besides the sun and moon, but it did not occur to them that the earth was a sixth such wanderer or planet.

Figure 23 shows that the planets fall naturally into two groups. The inner group of the four planets, Mercury, Venus, the Earth, and Mars differs from the outer group of planets, Jupiter, Saturn, Uranus, Neptune, and Pluto, in that they are smaller and have a greater density (with the exception of Pluto).

The planets all appear to shine, but they are cold bodies whose light, like that of the moon, is almost entirely the light reflected from the sun.

Just as the sun has a number of satellites, so the planets have varying numbers of satellites of their own, which are called moons.

Mercury Is the Dwarf among the Planets.

Mercury, having a mass about one-twentieth of the mass of the earth and having a diameter only half again as great as the moon's, is the dwarf among the planets with the possible exception of Pluto. Mercury is so close to the sun that it is visible only in a few certain positions in its orbit and then only shortly before sunrise or after sunset.

Mercury makes the circuit of the sun in eighty-eight days, and its time of rotation around its own axis is the same, so that its day is the same length as its year and it always presents the same face to the sun. It is too small for its gravitational attraction to hold atmospheric particles to its surface. This conclusion, based upon Newton's law of gravitation, is confirmed by the observation of *Aldrich*, who found that the earth with its atmosphere reflects about 44 per cent of the sunlight which reaches it, whereas the moon with no atmosphere reflects only 7 per cent. It was then found that Mercury also reflects only 7 per cent of the sunlight which reaches it.

Because Mercury is so close to the sun, it receives about seven times the radiation per unit area that the earth does. For this reason and because so little radiant energy is reflected, the side of Mercury facing the sun must be a parched desert too hot to support life, while the opposite side is always very dark and must be very cold inasmuch as there is no atmosphere or bodies of water to act as an equalizing medium. Certainly the conditions on Mercury would make life, as we know it, impossible.

Venus Is the Brightest of the Planets.

Taking the planets in the order of their proximity to the sun, we come now to the planet Venus. At times it appears as a bright evening star and at other periods as a brilliant morning star. It is nearly the same size as its nearest planetary neighbor, the earth. At times of greatest brilliancy, Venus can be seen in full daylight.

Inasmuch as Venus reflects 59 per cent of the incident light, it is known to have an atmosphere. The clouds which surround Venus are so dense that the few brief glimpses we have had of its body have been insufficient to enable man to determine the period of rotation about its axis. Spectroscopic evidence indicates that there is little oxygen in the atmosphere of Venus, which in turn indicates that there is little vegetation like that of the earth on Venus, because it is the process of

photosynthesis of plants on the earth that maintains the oxygen supply of the earth's surface.

It is probable that there are great oceans of water on Venus, which vaporize to form its dense clouds. Inasmuch as Venus is closer to the sun than the earth is, it receives more radiant energy, which must result in greater evaporation of water to form clouds.

Both Mercury and Venus show the phases characteristic of our moon. *Galileo* predicted that Venus would show these phases if it were to revolve around the sun rather than around the earth. His actual observations of the full and crescent phases of Venus were therefore very important.

The Earth and Its Satellite.

Next we come to the earth, or rather the earth and moon — a sort of double planet. Our moon is so much larger than the satellites of the other planets in relation to the sizes of their primaries that it may be considered as a small planet itself. Thus, though the earth and its history will be discussed in the next unit, a separate discussion of the moon may well be taken up at this point.

FIG. 24. The Caucasus and Apennine mountains on the moon at eighteen days. (Photograph from the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

The Moon Is Our Nearest Celestial Body.

The distance from the earth to the moon is about 240,000 miles. The diameter of the moon is about 2160 miles, or about one fourth that of the earth.

Large telescopes apparently bring the moon so close that objects only three hundred feet long can be seen on its surface. The visible surface of the moon has been carefully photographed and studied and its high mountains and wide plains named. The striking difference between the surface of the moon and that of the earth is the former's superabundance of craters, ranging from a quarter of a mile or less to

forty or fifty miles in diameter. The mountain chains and the crater walls rise three, four, and even five miles. The cause of these lunar craters is uncertain. Perhaps they were formed by huge meteors. Small craters have been formed in the earth's crust at least twice in fairly recent times, and possibly some craters of previous times have been obliterated by the erosive agents which are lacking on the moon. The unequal distribution of the craters and their concentration near the mountain ranges lead many astronomers to attribute their formation to ancient volcanic activity.

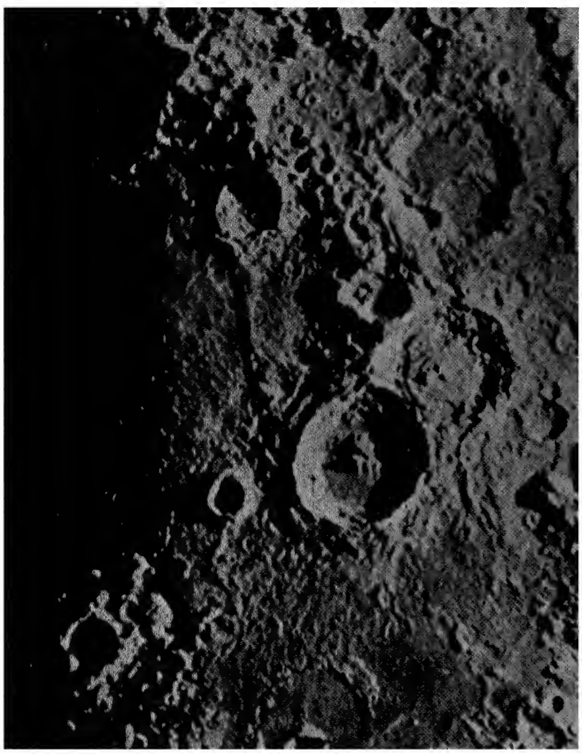


FIG. 25. Lunar crater Theophilus. (Photograph from the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

The density of the moon is only 60 per cent of the density of the earth and its mass only 1/82 as great. Its gravitational attraction is 1/6 that of the earth.

We are sure that the moon has no atmosphere because there is no refraction of light as stars appear from behind it. The masses of atmospheric particles and their velocities are known, and calculations based upon Newton's laws show that the moon could not hold such particles to its surface. The absence of erosion and spectroscopic evidence also indicate that these calculations are correct.

Inasmuch as the moon has no atmosphere, the side facing the sun must be much hotter than the Sahara desert, while the other side must be much colder than our coldest polar regions. Perhaps man may contrive to make a journey to the moon in the future; but its temperature extremes, complete lack of life, and oppressive silence would lead one to terminate his visit as soon as possible. With no atmosphere, man's voice and ears would be useless because sound would be impossible, and he would have to carry along his own supply of oxygen for life itself.

The light from the moon is, of course, reflected sunlight. The different phases of the moon (that is, the periodic change of shape from crescent to full and back again every twenty-nine days) depend upon the relative positions of the earth, moon, and sun, as shown in the diagram. It has already been noted that the planets closer to the sun than the earth pass through similar phases for the same reason.

To a man on the moon the earth would be bright because of the fact that it reflects sunlight just as the other planets do. This earthshine is in turn reflected back to the earth, so that when only a part of the moon receiving direct sunlight is visible, the rest of the side of the moon facing the earth becomes faintly visible because of reflected earthshine.

FIG. 26. Earth-lit "old moon in the new moon's arms." (Photograph from the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

The moon always turns the same face toward us, which means that the moon rotates on its axis once while it revolves once around the earth.

Eclipses No Longer Are a Source of Terror.

Modern man no longer is terrified by eclipses but looks upon their appearance at the precise place and time predicted by astronomers many years before as evidence of the true value of the scientific method. It is possible to predict to within a few hundred yards where the shadow of the moon will be located on the earth at any given second of time during the next few years.

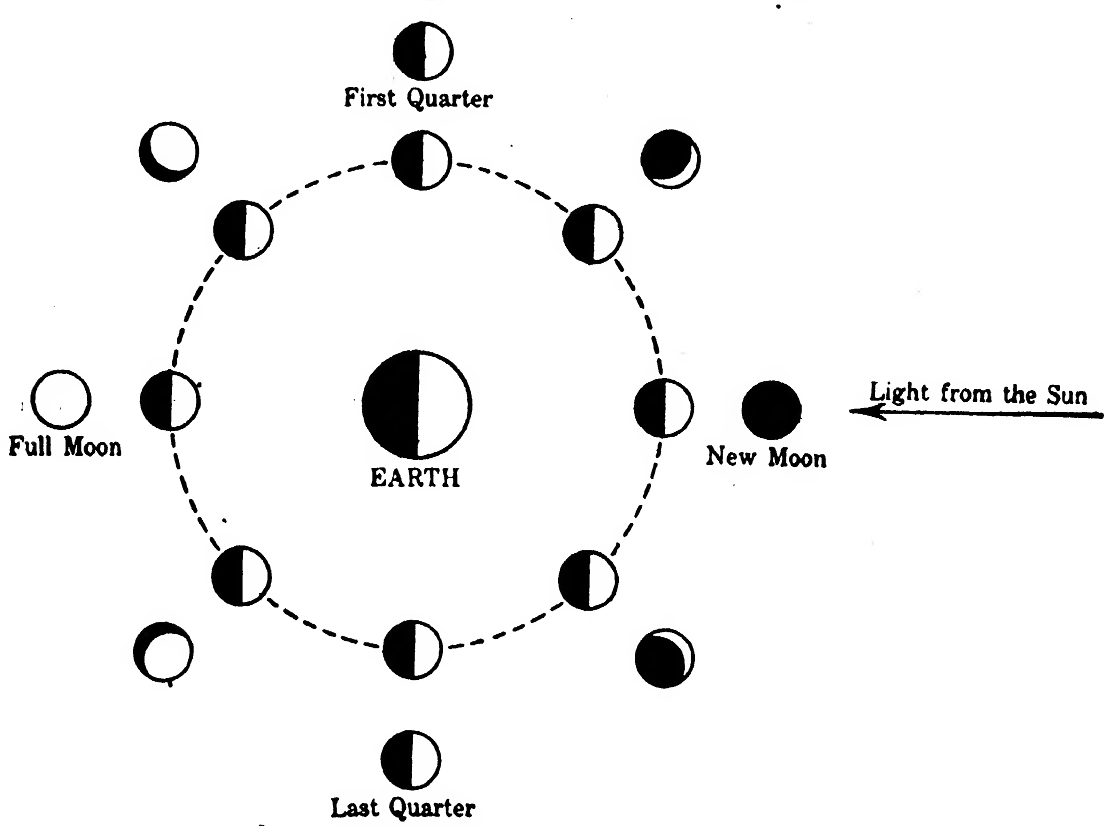


FIG. 27. The phases of the moon.

An eclipse is caused by the shadow of one body falling across another. When the moon lies between the sun and the earth, a shadow is cast on the earth and there is a solar eclipse; when the earth lies between the sun and the moon, a lunar eclipse results.

The only solar eclipse visible in the United States up to 1950 will be the eclipse of July 9, 1945. Under average conditions a solar eclipse lasts about two minutes, and the width of the shadow is less than a hundred miles.

Partial eclipses of the sun by planets, caused by their passage between the sun and the earth, are rare events called *transits*.

Total eclipses of planets or stars caused by the passage of the moon between them and the earth are called *occultations*. The occultations of the brighter planets — Venus, Mars, Jupiter, and Saturn — are very spectacular.

Mars Has Become Well Known as a Possible Abode of Human Beings.

Percival Lowell (1855-1916) observed regular markings on the surface of Mars which he believed to be canals built by a race of men to conduct water from the melting edges of the ice-capped poles to the warmer portions of the planet. Other observers have failed to see that these "canals" were so straight that they could not be explained in terms of ancient river valleys or other natural phenomena. The considerable seasonal changes in size, shape, and color of these markings, however, indicate that it is possible that vegetation exists on Mars. This idea is also supported by the fact that oxygen is found to be present in the atmosphere of Mars, although the amount present is not sufficient to support animal life as we know it.

Suppose that man could make a trip to Mars. What a sight-seeing excursion that would be! Phobos, the inner of Mars' two moons, would certainly be one of the main attractions. This moon, which is only ten miles in diameter, revolves about Mars at a distance of 3700 miles once every seven hours and thirty-nine minutes. Phobos will rise in the west and set four hours later in the east, passing through all of its phases during this time. No other known satellite revolves as Phobos does in a shorter interval than the rotation of its primary. On the other hand, Deimos, the second moon, will rise in the east and not set for several days because its period of revolution is only slightly greater than that of Mars.

The Asteroids Are a Group of Minor Planets.

Journeying outward from Mars, we come to the Asteroids, which include 400 or more minor planets. One of these Asteroids, Eros,

at rather long intervals comes within 14,000,000 miles of the earth. Hermes, a small Asteroid, about one mile in diameter, passes within 1,000,000 miles of the earth.

The largest of these Asteroids, Ceres, is 480 miles in diameter, while the smallest is only about one mile in diameter. It has been estimated that there are about 40,000 Asteroids, the total mass of which would amount to no more than 2 per cent of the mass of the moon.

Jupiter Is the Largest Planet.

The next planet is the largest member of the solar family, having a mass 314 times that of the earth. Because its density is only about one-fourth that of the earth, it follows that its volume is very much larger than the earth's; in fact, its diameter is more than eleven times as great.

Jupiter, like Venus, appears as a morning or evening star but shines less brilliantly than Venus. It may also appear as a midnight star like Mars or Saturn. Peculiar red spots on Jupiter's surface have enabled man to determine that its day is about ten hours long. This rapid rotation of such a large planet results in an appreciable bulging at the equator.

Because Jupiter is so far distant from the sun, it receives relatively little radiant energy. Its surface temperature is about $-100°$ C.

Jupiter has eleven moons, four of which are visible with a small telescope. These four satellites range in size from that of our moon to a size larger than that of the planet Mercury. The other seven satellites are quite small (ranging from twenty-five miles to a hundred miles in diameter) and can be detected only by use of the camera and the telescope. The two outermost moons are remarkable in that they revolve in a direction counter to that of all the planets and most of their satellites. It has been suggested that these two moons were Asteroids that came so close to Jupiter that they were unable to escape because of its gravitational attraction for them.

Saturn Is the Ringed Planet.

Saturn is the next largest planet, with a diameter nine times that of the earth but a density less than that of water. Like Jupiter, its day is short, and it bulges at the equator. Its temperature is still lower than that of Jupiter, as would be expected.

No one will forget the thrill of his first telescopic view of Saturn and its rings, for it is one of the most exquisitely beautiful objects in the heavens. This series of three rings, beginning about 7000 miles from the surface of the planet and extending outwards about 41,000 miles,

has been estimated to be not more than ten miles thick. These rings consist of small particles. According to one hypothesis, the rings came into existence as the result of tidal forces set up in a large satellite which came too near the planet.

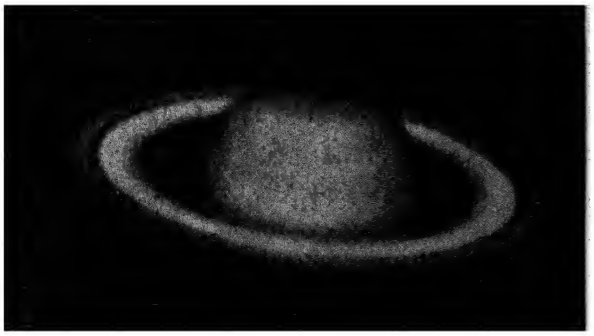


FIG. 28. Saturn. (Photograph from the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

Saturn has nine moons, the largest of which, Titan, is larger than our moon, while the smallest, Phoebe, is only about 150 miles in diameter. Phoebe was the first moon of any planet whose direction of revolution was observed to be counter to that of the planet. On December 16, 1943, Saturn will be in the best position for observation in the northern hemisphere, showing its widest opening of the rings at a time of maximum brilliancy.

Uranus Was Discovered by Accident.

Sir William Herschel (1738–1822), his sister *Caroline* (1750–1848), and his son *John* (1792–1871) made many contributions to astronomy. Sir William was a musician of unusual ability and made his living with his music. Astronomy was his hobby and he spent all of his spare time and money making telescopes and observing the sky. On the night of March 13, 1781, Herschel discovered Uranus when he happened by chance to be observing that portion of the heavens occupied by that planet.

The ancients did not know of the existence of any of the planets beyond Saturn, but modern astronomers have found three other planets, the most distant one being at a distance four times as great as the distance from the sun to Saturn.

It does not seem possible that either Saturn or Uranus could support life of any kind. Our chief interest in Uranus is in connection with the discovery of Neptune in the position predicted from observed discrepancies in the motion of Uranus.

The Discovery of Neptune Was a Triumph of Scientific Theory.

Newton's laws enable man to compute the paths of the heavenly bodies with amazing accuracy.

Uranus followed its predicted path until 1831, when its deviation began to be enough to observe. By 1841 the discrepancies were so great that one of two conclusions had to be drawn; either Newton's laws were not correct, or there was an unknown body influencing the

path of Uranus. Two mathematicians, *J. C. Adams* and *U. J. J. Leverrier*, working independently, calculated the position of this unknown body; and in 1846 the German astronomer, *Dr. J. G. Galle*, whom Leverrier asked to look for it, after a half-hour's search, discovered the planet Neptune less than a degree distant from the predicted position.

This was a great triumph for Newton's laws and greatly increased man's belief that his universe is one of cause and effect.

Neptune is the third largest planet and has only one satellite, which rotates in a direction counter to that of the planet itself. This moon is noteworthy in that it is larger than the planet Mars.

Pluto Is the Most Remote Planet.

The planet Pluto was discovered at the Lowell Observatory on January 21, 1930. *Lowell*, who died in 1916, and other astronomers had predicted the existence of this additional planet on the basis of exceedingly minute discrepancies in the path of Uranus that even the discovery of Neptune did not completely explain. It required a long time to discover Pluto because it is no brighter than 15,000,000 stars from which it had to be distinguished.

This discovery not only added to the confidence of astronomers in Newton's laws but also was a triumph for modern methods, for it had to be searched for photographically. Photography had begun to develop in Sir William Herschel's time, but comparisons of the motion pictures of today with those taken twenty years ago are sufficient to show the amazing progress which has been made in this field in our own generation.

Pluto is thought to be inferior to the earth in mass and size. It is about 3,670,000,000 miles from the sun, and it is estimated that its period of revolution around the sun is about 248 years.

STUDY QUESTIONS

1. Explain how the day and year on the planet Mercury can be the same.
2. Why does Mercury have such great extremes of temperature?
3. What peculiar feature is associated with the planet Saturn?
4. In what respect was the discovery of Neptune a scientific triumph?
5. What are Planetoids or Asteroids?
6. Discuss planetary moons briefly as to size, direction of rotation, number, and speed.
7. Would it be possible to see a skyscraper on the moon with a modern telescope?
8. Why is it that a high jumper could jump forty feet on the moon?
9. Why are the mountains on the moon steep and jagged?
10. What is a possible cause of the craters on the moon?

11. Describe some of the unusual conditions of theoretical life on the moon
12. Explain the phases of the moon.
13. How do the inner planets differ from the outer planets?
14. How is it known that Mercury has no atmosphere?
15. Which is the most distant planet?
16. Explain why Lowell believed in the existence of a ninth planet even before it had been discovered.
17. What causes eclipses?
18. What is the average duration of a total eclipse?
19. If Pluto and Jupiter moved with the same velocity, which would have the greater momentum, and why?
20. Would an object fall more rapidly toward the earth or toward the sun? Why?
21. Why does the moon appear to be larger than, or nearly the same size as, the sun?
22. How does a star differ from a planet?
23. Why can Mercury be observed only at twilight or at dawn?

UNIT II

SECTION 8

COMETS AND METEORS ARE OTHER INTERESTING MEMBERS OF OUR SOLAR SYSTEM

Introduction.

Meteors, the so-called shooting stars, which may be seen almost any clear night, and comets, which occasionally are so large that they can be seen with the naked eye, are of great popular interest.

Some of the comets and swarms of meteors travel in orbits around the sun and are, therefore, members of the solar system.

There Are Many Comets of Varying Size.

Several hundred comets have been observed. Most of these comets are so small that they are visible only with the aid of a telescope, but occasionally huge comets have appeared whose appearance was regarded as an omen of evil and disaster before their nature was understood.

FIG. 29. Morehouse's comet, November 16, 1908. (Photograph from the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

Halley's comet makes its journey around the sun once every seventy-five years, and its appearances have been recorded for some thousands of years.

Comets show a much greater range in size than do the planets. The head of the great comet of 1811 was about 1,125,000 miles in diameter, larger even than the sun. Many comets have heads about the size of Jupiter, *i.e.*, 80,000 miles in diameter. Halley's comet is 357,000 miles in diameter.

Comets Move in Well-defined Orbits around the Sun.

The orbits of about four hundred comets are fairly well known, so that the time of reappearance of such comets can be very accurately predicted in some cases. Some of the comets have orbits that carry them far outside of the orbit of Pluto.

The shortest period of revolution around the sun is about 3.3 years, that of Encke's comet, while others travel along orbits that require thousands or even hundreds of thousands of years for one revolution.

The Nature of Comets.

The masses of the comets are much less than those of the planets; comets with the largest mass probably weigh less than our atmosphere. Within the heads of most comets nuclei are observed. These nuclei are observed to consist of a swarm of meteors. Some of these swarms display a definite nucleus of their own.

These nuclear swarms of meteors are thought to be surrounded with an envelope of gas, so rarefied that stars can be readily seen through it.

Comets Are Visibly Affected as They Approach the Sun.

The speed of comets is greatly increased as they approach the sun; at the same time the head contracts, and, perhaps because of this increase in speed, a tail begins to form. The tail becomes longer as

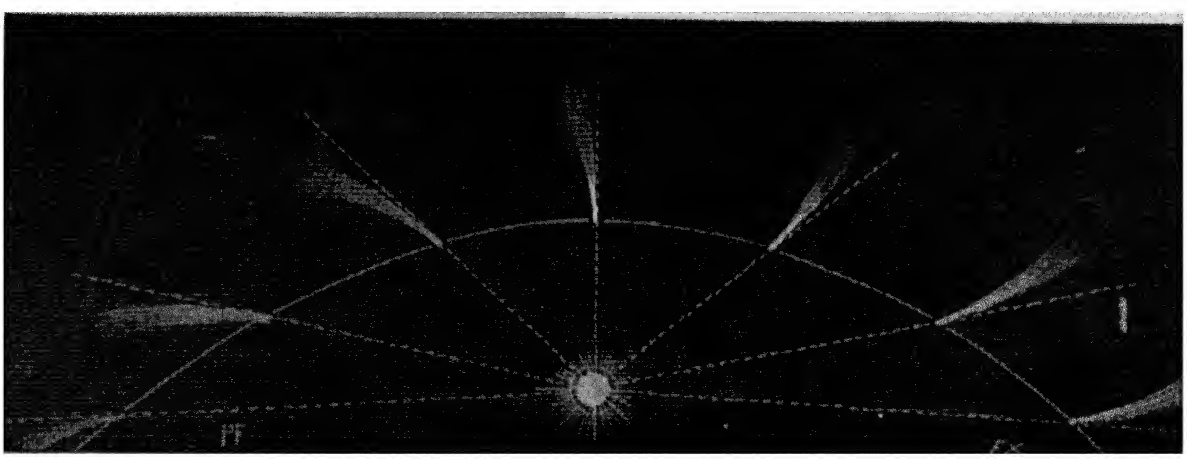


FIG. 30. Variations in comets' tails. (From G. F. Chambers, *Story of the Comets*, Clarendon Press, Oxford, England.)

the comet gets closer to the sun and always points away from the sun; as the comet leaves the sun its tail actually precedes its head. Sometimes the comets' tails extend a length of as much as two hundred million miles, while they spread out to a maximum of about ten million miles. The tail probably consists of gas particles which are driven outward by the pressure of the radiations from the sun. It is quite probable that this gaseous material driven away from the head is

STUDY QUESTIONS

1. How did the ancients consider comets?
2. What causes the tail of a comet?
3. What is the position of the comet's tail with reference to the sun? What causes this?
4. What is the generally accepted idea of the composition of a comet?
5. How large are meteors?
6. Why do meteors get hot?
7. How far from the earth do meteors usually appear and disappear?
8. What are the three types ot meteorites? Of what is each composed?
9. Give some examples to show the force of the impact when a meteor collides with the earth.
10. Why do meteoric showers appear periodically?
11. What information may be gained from the observation of the trails of meteors?
12. What does the fact that certain meteorite swarms follow the paths of disintegrated comets suggest?
13. The following hypotheses concerning the origin of meteorites have been suggested: (1) they were thrown up by volcanoes; (2) they were produced by volcanoes on the moon; (3) they are of the same origin as meteors. Suggest some possible observations that might be made to prove the truth or untruth of each hypothesis.

UNIT II

SECTION 9

ASTRONOMICAL MEASUREMENTS ARE USED TO MEASURE TIME, TO FIX THE CALENDAR, AND TO AID IN NAVIGATION

Introduction.

Time-keeping and navigation are two important practical applications of astronomy. Navigation will be discussed in detail in Unit V, Section 9.

Measurement of Time.

The measurement of time is based on the laws of motion. Two intervals of time are equal if, during each, the earth rotates through equal angles.

Foucault's Pendulum Proved That the Earth Rotates.

In 1851 *Léon Foucault* hung a long pendulum with a heavy bob from the top of the dome of the Pantheon in Paris and set the pendulum swinging. The direction of the swinging was carefully marked. In a short time it was observed to have changed its direction with respect to the building at the rate of about eleven degrees per hour. The pendulum could not have changed its direction without a force acting on it. But no force had been applied, so the only conclusion was that the earth, as a result of its rotation, changed its position relative to the pendulum and thus caused the apparent change in the direction of the swing of the pendulum.

The Rotation of the Earth Is Our Master Clock.

Our watches and clocks are regulated to agree with a reference clock in an observatory, and this clock is regulated in turn by the earth's turning round and round on its axis. Is this master clock perfectly reliable? There is evidence that the speed of rotation of the earth is diminishing and that the length of the day is increasing at the rate of one or two thousandths of a second per century, but this change in our master time clock is of no practical importance to the everyday prob-

lems of time. The tides act as friction brakes to slow down the rate of the earth's rotation. There are also sudden and unpredictable changes in the rate of rotation of the earth, perhaps because of expansion or contraction of the earth due to variations in solar radiations; but these changes never throw the earth off schedule more than a few seconds.

Primitive Man Told Time by the Sun and Moon.

Primitive man told time day by day in terms of the relative positions of the sun and earth. Later he felt the need of a timepiece that could

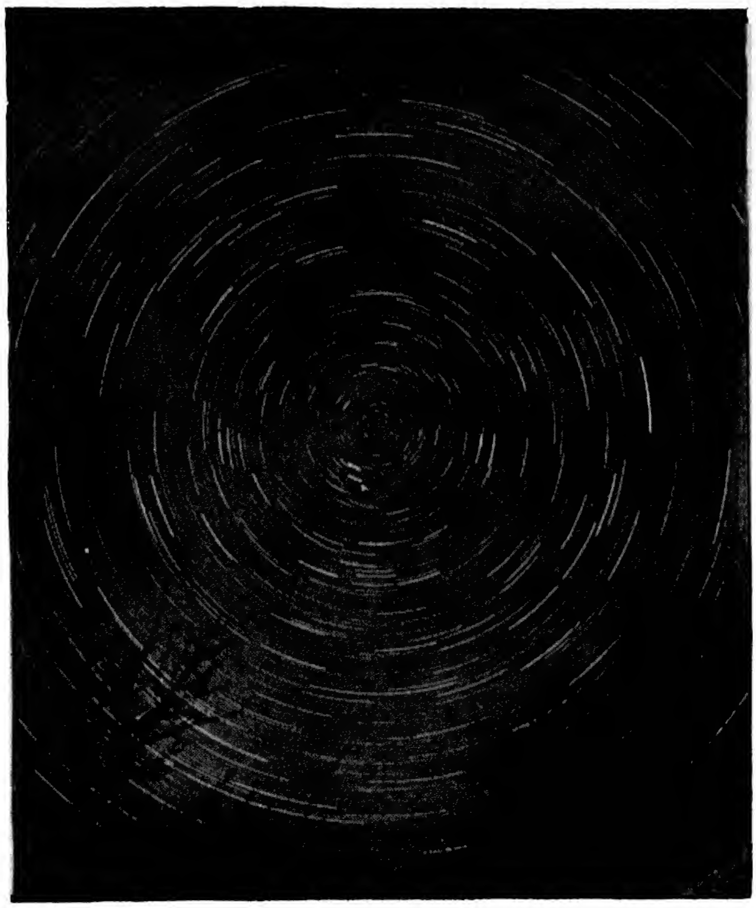


Fig. 33. This time exposure of the stars at the north pole shows the rotation of the earth. (From Moulton, F. R., *Astronomy*, The Macmillan Company.)

indicate more than a single day. Again man looked to the sky and found the desired timepiece. He perceived the changes in the shape of the moon and its failure to appear from time to time. He also observed that these changes occurred over and over again — always in the same order — and the same number of days apart. The moon thus made it possible to fix a future date. Its name means "The Measurer of Time," and from it comes our word "month."

Sidereal Time Is the Hour Angle of the Vernal Equinox.

The sidereal day equals the interval of time required for the earth to make one complete rotation.

The sidereal day is about four minutes shorter than the ordinary solar day, and it is divided into twenty-four sidereal hours. Sidereal noon occurs at the moment the vernal equinox is on the meridian. This time occurs at different times of the day or night at different times of the year. Astronomical clocks regulated to sidereal time are called sidereal clocks.

Sidereal time is actually obtained by observing the positions of fixed stars, called "clock stars." The transit is used in navigation in making these observations. All sidereal days are of the same length. Inasmuch as our activities are based largely on the position of the sun in the sky, sidereal time is inconvenient.

The stars rise four minutes earlier from night to night, or about half an hour earlier from week to week. For this reason the constellations move slowly westward across the evening sky as the seasons go around.

The Sun Is a Poor Clock.

The earth moves through a complete revolution around the sun in about 365¼ days, but this motion is not uniform, because the path of the earth is an ellipse rather than a circle. It requires 186 days for the earth to pass from vernal equinox to autumnal equinox, March 21 to September 22, and only 179 days to pass to vernal equinox again. For this reason there are times of the year when the sun time runs nearly fifteen minutes slow, and there are other times when it runs fifteen minutes fast.

We use as our timekeeper not the real sun, but an imaginary one whose apparent motion is uniform.

Standard Time Became a Necessity in the Age of the Machine.

With the development of transportation in countries as extensive as the United States, it was necessary to adopt standard time, for otherwise communities on different longitudes or meridians would have different local times.

Standard time was officially adopted by the United States in 1884. The railroads divided North America into five standard time belts, each belt to the west being one hour slower than its eastern neighbor. Radio broadcasts have made us quite familiar with the names of most of these time belts, which are given as follows:

1. Atlantic, which includes Newfoundland and a small part of Canada
2. Eastern, which includes states east of a line running roughly from Toledo, Ohio, to the western boundary of Florida
3. Central, which includes states west of this line to about the western boundaries of the Dakotas, Nebraska, Kansas, Oklahoma, and Texas

4. Mountain, which includes all states from this line west through the Rockies
5. Pacific, which includes all states west of the Rockies to the Pacific Ocean.

These lines are roughly about 1/24 of the circumference of the earth, or about 1040 miles apart on the equator. Actually these time belts are irregular, because changes have been made at different points to suit local business conditions.

A traveler going westward sets his watch back an hour at certain intervals. Obviously, this process involves a day's change at some point. By international agreement a line was chosen as the "international date line"; it is in the Pacific Ocean, and ships crossing it westward must skip a day. If it is Monday at 3 P.M. when the ship reaches the line sailing westward, it will be Tuesday at 3 P.M. when the ship has crossed it. When traveling eastward, the same day is counted twice. Thus one may read in a Monday newspaper about events in Japan dated Tuesday.

Daylight-saving Time Provides More Daylight Living in the Summer Months.

Daylight-saving time is usually established by advancing the standard time one full hour.

Knoxville, Tennessee, is 750 miles east of Amarillo, Texas. Both cities use central standard time, but the sun actually rises in Amarillo nearly an hour and a half later than it does in Knoxville. Amarillo may be said to have daylight-saving time while it uses standard time. On the other hand, the people living in Knoxville would lose an hour of out-of-door daylight recreation in the summer if they did not adopt daylight-saving time. The cities in the eastern half of a standard time zone are the ones which would profit from daylight-saving time.

Many Instruments Have Been Used in Reckoning Time.

The Sundial. The earliest sundial, dating back as far as 2000 B.C., was based on the principle of a vertical rod or gnomon casting a shadow on a flat plane. The surface of the plane was marked, so that the time of day could be read from the position of the shadow.

Such sundials were not accurate because they failed to take into account the apparent motion of the sun from north to south, which changed the position of the shadow with the advance of the seasons.

The Modern Sundial. The modern sundial is based on the same principle as its predecessors, but the gnomon which casts the shadow is inclined from vertical to an angle equal to the latitude of the place

where the dial is erected. This change in the design of the sundial corrects for the apparent movement of the sun in a north and south direction.

Mechanical Devices. The need arose for an instrument that would measure time both day and night, independently of the sunlight.

1. *Tapers* graduated into equal parts were once used to indicate time, inasmuch as they burned at a roughly constant rate.
2. *The clepsydra* was a simple measuring device which depended upon the time required for a given amount of water to trickle through a hole in the bottom of a suitable container. The modern hourglass or sandglass is a variation of the clepsydra.
3. *More complicated devices* depended upon the motion of a pointer connected by gears to a float that was raised as the vessel in which it rested was gradually filled with water.
4. *Power-driven clocks* superseded the water clocks because they removed difficulties involved in maintaining a water supply that would not freeze in the winter and because water clocks could not be used at sea. (In navigation, longitude can be determined *only* if one knows the time somewhere else.)
5. *The modern electric clocks*, which are rapidly replacing other types of clocks, are run by the alternating current whose pulsations are checked by master clocks at the power plants. In reality, then, all electric clocks are merely devices to receive and indicate time signals transmitted by alternating current from a master clock. Most power companies generate 60-cycle current, that is, current which alternates exactly 120 times a second. Inside an electric clock is a tiny motor synchronized with the generators in the powerhouses.

The Calendar.

Julius Caesar in 45 B.C. introduced the Julian calendar invented by *Sosigenes*. He used 365¼ days as the year and invented the leap year to take care of the quarter-days. The Julian year is too long by 11 minutes and 14 seconds. In 400 years, this variation would amount to 3 days. In the sixteenth century, this error had mounted to 11 days. *Pope Gregory*, at that time, dropped 10 days from the calendar, but not without considerable opposition.

The Gregorian calendar provides that century years are not leap years unless they are divisible by 400, thus making another such radical revision of the calendar unnecessary, because our present year is too long by only 26 seconds. Thus the Gregorian calendar provides for

The Gregorian calendar was adopted by England in 1752, by Russia in 1917, by Yugoslavia and Rumania in 1919, and by Greece in 1923, at which time 13 days had to be dropped from the calendar.

Julius Caesar's calendar provided that all even-numbered months should have 30 days except February, which was to have only 28 days except in leap years, while all odd-numbered months were to have 31 days. The Roman Senate honored Julius Caesar by naming July after him. Later *Augustus Caesar* had the month of August named after him and changed the length of the month to 31 days in order to have it equal Julius Caesar's month in number of days. This change unbalanced the length of the quarters, so a day was taken from September and from November and added to October and December. Many people believe that we are about due for a new deal as far as the calendar is concerned. Our present calendar, thus handed down to us by the Caesars and Pope Gregory, possesses the following disadvantages: Months, quarters, and half-years are not of equal length and do not contain whole numbers of weeks, thus making calculations of salaries, rents, interest, and other business transactions inaccurate when based on monthly, quarterly, or semi-yearly periods. The calendar is not perpetual, and holidays and other principal events occur on different days of the week from year to year.

Many improvements in the calendar have been recommended. One of them is a year of 13 months — 28 days each — the 13th month to be named Sol, and New Year's Day to be the extra day not belonging to any month; in leap years another day is to be added between February and March.

In 325 A.D. the Council of Nice adopted the rule for Easter, which fixes it as the first Sunday after the 14th day of the nearly full moon which occurs on or immediately after March 21.

EASTER DATES

1942	April 5	1947	April 6
1943	April 25	1948	March 28
1944	April 9	1949	April 17
1945	April 1	1950	April 9
1946	April 21	1951	March 25

Navigation.

Prior to 1760, when the chronometer, merely a very accurate clock, was invented, there was no way of determining longitude at sea because there was no way of carrying the time of the home port on board ship.

Distances east or west of Greenwich are determined in degrees of longitude, while those north and south of the equator are estimated in degrees of latitude.

To determine longitude, it is necessary to know but two things: first, the local mean time of the place whose position is to be determined; and second, the solar time of the standard meridian, which is usually taken as Greenwich, England, time. The ship's chronometer gives accurate Greenwich time, which may now be obtained also by radio. The sextant is used to measure the apparent solar time and also to measure the latitude.

STUDY QUESTIONS

1. What are the four times used today?
2. What is sidereal time?
3. How does sidereal time compare with the mean solar time?
4. Why is the international date line necessary?
5. What is standard time?
6. How many standard time belts are there in the United States? Name them.
7. Is the time set forward or backward as one moves westward? Why?
8. Describe an experiment to prove that the earth rotates.
9. Explain the necessity for and the meaning of leap years.
10. What kind of time is measured by ordinary electric clocks?
11. Why is there a need for calendar reform?
12. Tell how July and August received their names.
13. What is a chronometer, and of what value is it to navigation?
14. Differentiate between apparent sun time and mean sun time.
15. Why did standard time become a necessity with the advent of the machine age?
16. How does our calendar differ from that set up by Julius Caesar?
17. When was the method of reckoning Easter decided upon?
18. What type of time is obtained with a sundial?

UNIT III

CONTINUOUS CHANGES IN THE EARTH'S SURFACE HAVE BROUGHT ABOUT CONDITIONS WHICH MAKE POSSIBLE THE LIFE OF MODERN MAN

INTRODUCTION TO UNIT III

In speaking of the earth, geologists refer to the outer solid portion as the lithosphere, the oceans, etc. as the hydrosphere, and the gaseous envelope which surrounds the earth as the atmosphere. Inasmuch as the earth rotates daily in the path of the sun's radiant energy, it is heated unequally from day to night. This unequal heating of the earth produces changes in the densities of the hydrosphere and atmosphere, which, under the influence of gravity, result in local circulations in these spheres. A more important cause of circulation in the atmosphere and hydrosphere is the difference between the radiation received at the poles and that received at the equator. The rotation of the earth affects the direction of the above circulation. The radiant energy of the sun also brings about the evaporation of water. The water vapor so formed is transported by air currents to colder places, where it condenses as rain. Thus the energy of the sun brings about weather changes, winds, and rains, which constitute the physical bases for the changes in the earth's surface known as gradation.

Gradation is the geological activity which tends to level the surface of the lithosphere; it consists of two processes: degradation, or wearing-down of the higher places, and aggradation, or building-up of the lower places. It seems probable that the earth underwent readjustments in volume, due to rearrangements of the rock materials under the stress of pressure, and that the surface therefore was thrown into wrinkles, thus forming mountain ranges. These mountain ranges were in turn torn down by various agents of erosion with a redistribution of pressure on the surface that resulted in upheavals of new mountain ranges. Some people have attributed this wrinkling process to the gradual

cooling of a formerly much hotter body, but modern knowledge suggests that it is a result of tremendous pressures in the deep interior. These very slow gradational and mountain-building changes brought valuable minerals to the surface, deposited layers of salts, rock, and coal, and finally produced the soil required for our crops.

UNIT III

SECTION 1

THE ORIGIN AND AGE OF THE EARTH ARE SUBJECTS FOR MUCH SCIENTIFIC SPECULATION

Introduction.

Modern exploration and study of changes now taking place in the earth's crust give valuable information concerning the probable history of the earth. This section presents a brief résumé of the conclusions concerning the origin, age, and development of the earth which the geologist and his fellow-scientists have pieced together. The picture presented lacks many details, because geology, the study of the earth, is a comparatively new science.

Three Scientific Hypotheses to Account for the Earth's Form Have Emerged.

The Nebular Hypothesis. This hypothesis, sometimes called the Laplacian hypothesis in honor of *Simon Laplace*, who formulated it in 1796, assumes that the solar system was formed by the condensation of a vast cloud of hot gas. As it condensed, large portions of material separated as rings around the center, which remained as the sun. In the same way these portions of the nebula formed miniature solar systems of their own, thus forming the planets with their moons. Anyone who doubted this satisfactory theory was invited to have a look at Saturn and its rings, which were supposed to represent the early stage in the formations of moons.

Many valid objections to this theory were advanced as more detailed knowledge became available. One of the objections was based on the observation that the two outer moons of Jupiter and the outer moon of Saturn revolve in orbits opposite to the direction of the revolution of the planets themselves. This change in direction could not have taken place if these moons were formed from the body of the planet, according to Newton's laws. Again, according to this theory, satellites should rotate slower than the parent planet, but they actually rotate faster in some cases.

As evidence piled up against it, this theory was finally given up even by its fondest adherents.

The Planetesimal Hypothesis. The planetesimal hypothesis, advanced by *Chamberlin* and *Moulton* of the University of Chicago, superseded the nebular hypothesis. This theory, like all others, retains the central idea that the whole solar system began as one large body but differs from the nebular theory in the belief that the force which caused the separation of the planets and other smaller bodies came from without. Another star is thought to have come near the star of which our sun is the residue. It did not come close enough to produce a collision but did come close enough to exert such a force of attraction on the outer portions of the sun that large arms were shot out as it revolved near the passing star. These gases then cooled to form solid meteorites, or planetesimals. The planets and their satellites were originally just extra-large meteorites that steadily grew by attracting to themselves the still smaller particles.

This theory differs from the nebular hypothesis in that it assumes that the earth was built up from smaller solid particles which were cold, that the earth grew hotter due to increasing pressures developed by the gradual accumulation of mass, and that the earth originally had no atmosphere.

The Tidal Theory. The tidal theory, advanced by the British astronomers, *Sir James Jeans* and *Harold Jeffreys*, in 1919, is a variation of the planetesimal hypothesis that seems to be satisfactory today. According to this theory, the planets were torn from the sun, possessing masses approximately as we know them today, as the result of tides produced in the surfaces of the two suns as they came very close to each other.

In any event, it is probable that the origin of our earth was no ordinary, everyday cosmic affair. Stars do not come near each other very often, and when they do it is unlikely that they do so in such a way as to form planets like those of our sun. But here again we may be all wrong. Perhaps many stars have planets too distant to be observed. For instance, a man on the nearest star, Alpha Centauri, would have to have a telescope a thousand times more powerful than our best telescope to be able to see the sun's largest planet, Jupiter.

Undoubtedly the present hypotheses will be revised from time to time as additional knowledge becomes available. It is important to note that scientists are just as anxious to disprove these hypotheses as they are to prove them. Their acceptance of them is real, but tentative, because they are ready to reject them for better hypotheses at any time. There is no more fundamental test of the degree to which one is

influenced by the scientific attitude than one's attitudes toward his hypotheses.

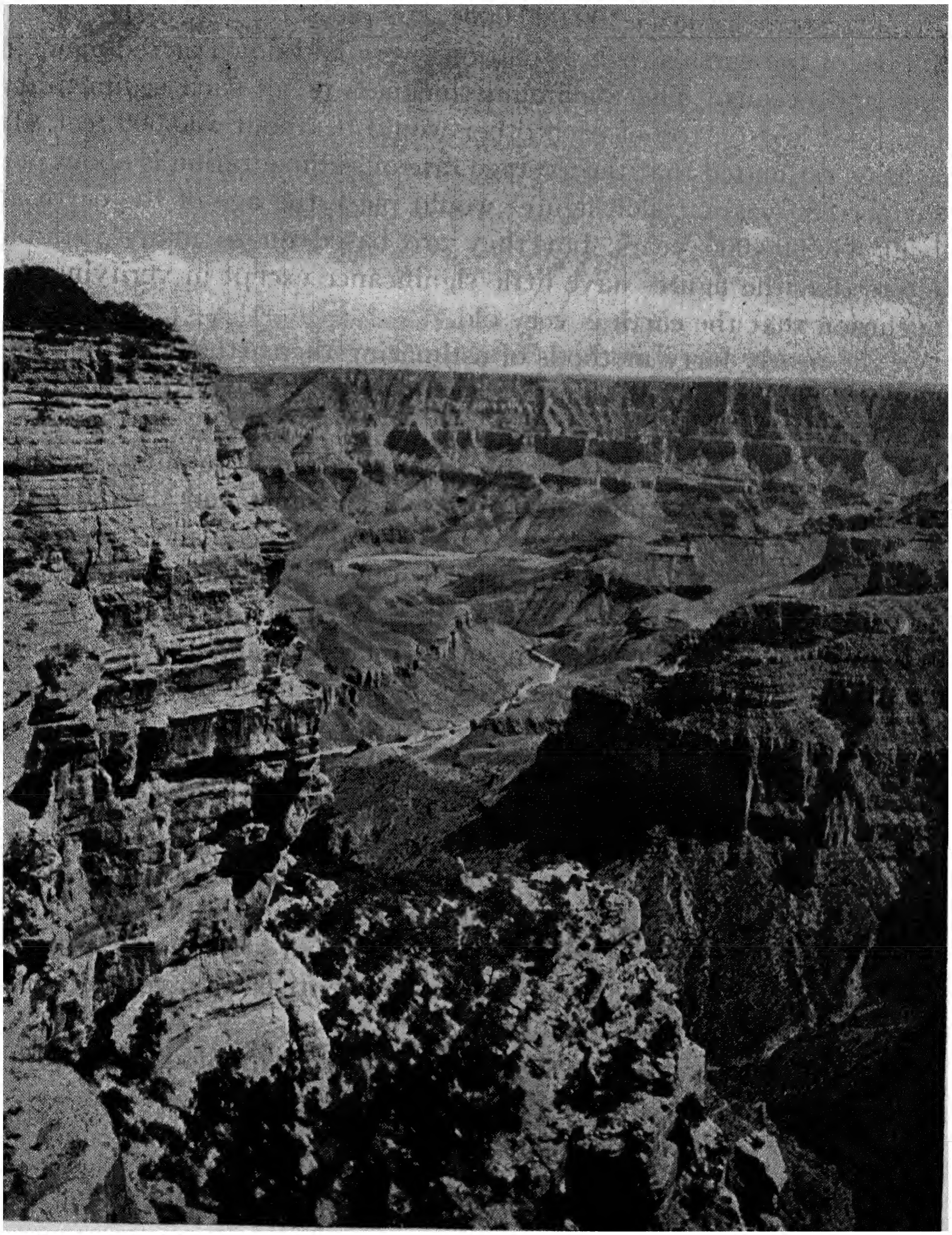


FIG. 34. The Colorado River and the Grand Canyon from the north rim at Cape Royal, Arizona. (Courtesy of the Union Pacific Railroad.)

The Age of the Earth Has Been Estimated by Many Methods.

At one time all of the water in the earth was probably fresh water. The salt in the oceans was brought there by the rivers from the land.

It is possible to determine experimentally the present rate at which salt is thus being added to the oceans and also to determine the present total amount therein. On the basis of such figures, the earth has been calculated to be at least 100,000,000 years old.

Some of the earth's rock formations were laid down as sediment in lakes and oceans. The maximum thickness of all such sedimentary deposits if laid on top of each other would be about 500,000 feet. It has been estimated that the average rate of sedimentation is about one foot per 880 years. Such figures would place the age of the earth at about 440,000,000 years, but they are based on so many variable factors that the figures have little significance except in verifying the conclusion that the earth is very old.

Of the nearly forty methods of estimating the earth's age, only one is potentially accurate. This is the method based on the study of radioactivity. Radioactive elements disintegrate to form lighter elements. The present rate of this disintegration is definitely known. By analysis, the amounts of the original elements and their disintegrated products in a given rock can be determined, and from these data, assuming no initial products of disintegration, the age of the rock can be calculated. A given stratum of rock can be recognized by the fossils which it contains and by other methods, and the age of any stratum which contains igneous rocks can be determined by determining the age of these rocks by the radioactive method. Radioactive examinations of the earth's crust indicate that its age lies between 1¾ and 3½ billions of years. Einstein by other methods, however, calculates that the earth is 10,000,000,000 years old.

Radioactive examination of many meteorites, some probably of interstellar origin, has led some scientists to conclude that the whole universe was born out of what came before it at about the same time that our solar system is thought by some scientists to have originated, about 1800 million years or more ago.

These various scientific estimates are based on methods which differ in precision, but they all lead to the conclusion that the earth is very old.

Lemaître's Hypothesis Is That the Universe Started as One Giant Atom about 1800 Million Years Ago.

Spectroscopic evidence leads to the theory of an expanding universe because distant nebulae seem to be receding from us at terrific speeds. Calculations based on the measured speeds and directions of motion of many nebulae, assuming that they all started moving from one point at a certain time in the remote past, being launched with their present

speeds and in their present directions by a tremendous explosion, yield the conclusion that the hypothetical starting-time was 1840 million years ago.

The agreement of this figure with figures concerning the age of the earth obtained by entirely independent methods is very striking. *Lemaître* explains this agreement by use of the hypothesis that the universe started out as a giant atom, which broke up some 1800 millions of years ago to form supergalaxies, galaxies, stars, and our solar system.

STUDY QUESTIONS

1. Why is the Laplacian hypothesis no longer tenable?
2. State the hypothesis of the origin of the earth which is most acceptable today.
3. Using the hypotheses concerning the origin of the earth as examples, show how scientists view hypotheses.
4. List some of the consequences of the unequal heating of the earth due to its rotation.
5. Define gradation, degradation, and aggradation.
6. Discuss the rate at which changes take place on the earth's surface.
7. List several ways in which the age of the earth has been estimated. What generalization can you derive from these estimates?
8. Explain the formation of mountain ranges.
9. Discuss the theory of an expanding universe. What data are there to support this theory?

UNIT III

SECTION 2

THE NATURE OF THE EARTH INTRIGUES THE CURIOSITY OF MAN

Introduction.

It is only natural that the insatiable curiosity of modern man should lead him to explore every portion of the earth's surface, often risking starvation or freezing to death in Arctic and Antarctic explorations, or putting his last ounce of strength into the attempt to climb just one foot higher on Mount Everest. Marvelous underground caverns, fuming volcanoes, tropical jungles, and desert "no-man's lands" having been conquered, man next directed his curiosity to vertical explorations of the three spheres: the gaseous envelope, called the *atmosphere;* the liquid layer, called the *hydrosphere;* and the solid *lithosphere* and *centrosphere.* The fact that these three layers — solid, liquid, and gaseous — are in contact with each other and are heated by the sun is responsible for the continuous changes in the surface of the earth. It is at this point of contact of land, water, and air that man has lived.

This section will attempt to outline briefly how man has been able to explore these three spheres and what he has learned about them.

The Atmosphere Consists of the Troposphere and the Stratosphere.

The duration of twilight indicates that the atmosphere reaches to a height of about 40 miles. Meteor flights give evidence that there is some atmosphere as high as 90 to 185 miles. Auroral displays suggest that the atmosphere dwindles down to a very low density at a height of 600 miles.

The stratosphere is that portion of the atmosphere which lies above the region of circulation. Lack of circulation results in few clouds or weather disturbances in this region.

The troposphere is the region near the earth where there is continual disturbance, and the tropopause separates the troposphere from the stratosphere. The tropopause is about 11 miles high over the equator and 4 miles high over the poles.

Man Has Made Many Efforts to Study the Nature of the Atmosphere.

Morton and *Somervell* climbed nearly to the top of Mount Everest in 1924 and found the atmosphere so rarefied above the 21,000-foot level that they had to carry oxygen tanks for their attempt to climb to the peak at 28,100 feet.

In 1931 *Piccard* and *Kipfer* reached a height of 52,462 feet (nearly 10 miles) in an airtight aluminum globe gondola carried by a balloon. Since Piccard's ascent many other attempts have been made. Some have been successful, and others have ended in disaster.

In 1933 *Settle* and *Fordney* established an official record of 61,237 feet. The highest elevation reached by man in an airplane was 47,806 feet, attained by *Kokinaki* in the U. S. S. R. in 1935.

The United States Army-National Geographic Society stratosphere flight made by *Stevens* and *Anderson* on November 11, 1935, attained a record height of 72,395 feet for a balloon with human passengers. This was more than two miles higher than the record made by Settle and Fordney in 1933.

Scientific recording instruments have been carried for observations by balloons to a height of 21.78 miles.

The Atmosphere Is Composed of a Mixture of Gases.

The earth's atmosphere is composed of an intimate mixture of gases whose composition at sea level is quite constant except for the water-vapor content, which varies between wide limits. One of the reasons why the atmosphere has a nearly constant composition even though it is a mixture is that it is mobile and expands and contracts with temperature changes, thus developing circulation which keeps it thoroughly mixed. The composition of dry air near sea level is as follows:

	By Volume	By Weight
Nitrogen	78.03	75.58
Oxygen	20.99	23.08
Argon	0.93	1.28
Carbon dioxide	0.035	0.053
Hydrogen	0.01	0.001
Rare inert gases (other than argon)	0.0024	0.003

Other constituents, such as ammonia, sulfur dioxide, hydrogen sulfide, dust, and bacteria, are present in small amounts which vary with local conditions.

The composition of the atmosphere is very significant as far as man is concerned because plant life produces foods from the carbon dioxide

of the atmosphere and man breathes oxygen to burn these foods in his body to furnish energy.

The weight of the atmosphere is about 5,000,000,000,000,000 tons, or 30,000,000 tons per square mile.

In temperate regions on the average of at least 100,000 tons of water vapor are present over each square mile of the earth's surface. In the tropics several times this amount of water vapor may be present, because warm air can hold much more water vapor than cool air.

At high altitudes mountains such as Mount Everest are always very cold. At thirteen miles above sea level the temperature is 80° F. below zero. At this height there is very little matter to absorb heat. At this altitude the atmosphere is so rarefied that no breathing organisms could survive unless they took a supply of compressed air or oxygen with them. Ninety-five per cent of the atmosphere is contained in the layer within thirteen miles of sea level.

The Atmosphere May Once Have Had a Different Composition.

It is quite possible that all of the water on the earth was once contained in the atmosphere at a much higher temperature than that which now exists on the earth's surface. Perhaps the atmosphere likewise contained much more carbon dioxide and less oxygen than it does today. Plants build their body structures largely out of the carbon dioxide that they take from the air and the water and its dissolved salts taken from the soil. By this process oxygen is added to the atmosphere. On the other hand, animals use oxygen from the air to burn the plants which they eat to produce heat and other forms of energy. Carbon dioxide is added to the air by the process of respiration, as well as by the decay of plant and animal tissues and the burning of fuels. It is removed from the air, on the other hand, by its reaction with substances in water solution to form vast deposits of carbonates such as limestone and marble. Today these processes seem to have reached a condition of equilibrium. At least so we trust, for a very small decrease in the carbon dioxide content of the air would result in the extinction of all plant life.

Whole mountain ranges of carbonates exist; and tremendous deposits of peat, coal, and oil represent huge amounts (at least 30,000 times as much as in the air today) of carbon which must have been present at one time or another in the earth's atmosphere. The very luxuriant plant growth which was responsible for these coal deposits may be attributed to the higher temperatures and higher carbon dioxide content of the atmosphere at that time. Undoubtedly plant growth added a great deal of oxygen to the air during these periods.

The Hydrosphere Has Been Explored Too.

The liquid sphere of the earth is extraordinary in that it may evaporate and become a part of the atmosphere or freeze and become a part of the lithosphere. Not only that, it can also dissolve some of the atmosphere and thus support marine life, and it has dissolved so much of the lithosphere that ocean water now contains about 3½ per cent solid matter, in solution consisting largely of chlorides and sulfates of sodium, magnesium, and potassium.

The water portion of the earth is spoken of as the hydrosphere. The pressure of water increases one atmosphere, *i.e.*, 14.7 pounds, for every 33 feet of depth. At a depth of one mile the pressure is over a ton per square inch. Man cannot go to depths greater than 300 feet safely with diving suits, but *William Beebe* and *Otis Barton* descended more than a half-mile into the ocean in a strong steel sphere with fused quartz windows, called a bathysphere.

William Beebe's bathysphere developed a leak in a preliminary test in which it was let down into the ocean empty. The tremendous pressure of the ocean depths can be imagined from the following account which Beebe recorded in his book, *Half Mile Down.*[1]

> I began to unscrew the giant wing bolt in the center of the door and, after the first few turns, a strange high singing came forth, then a fine mist, steam-like in consistency, shot out. . . . I cleared the deck in front of the door of everyone, staff and crew. . . . Carefully, little by little, two of us turned the brass handles. . . . Suddenly, without the slightest warning, the bolt was torn from our hands, and the mass of heavy metal was shot across the deck like a shell from a gun. The trajectory was almost straight and the brass bolt hurtled into the steel winch thirty feet away across the deck and sheared a half-inch notch gouged out by the harder metal. This was followed by a solid cylinder of water, which slackened after a while to a cataract, pouring out of the hole in the door, some air mingling with the water, looking like hot steam, instead of compressed air shooting through ice-cold water. If I had been in the way, I would have been decapitated.

Greater depths can be explored only by the indirect means of depth-sounding devices and dragnets which bring to the surface many odd deep-sea fish. Below 3000 feet the ocean is dark as night, and many of these deep-sea fish have amazing lighting systems of their own.

The greatest ocean depths so far recorded are:

	Feet
Mundanae, near the Philippine Islands	35,400
South Pacific Ocean	30,930
Milwaukee Deep in the North Atlantic Ocean	28,680
Southern Atlantic	26,575
Indian Ocean	22,968

[1] Harcourt, Brace and Company, 1934, pp. 153–154.

Inasmuch as warm water is less dense than cold water, the ocean depths are nearly ice-cold (4° C.) even in the tropics.

The Earth Is Round.

The earth is a typical planet, and other planets are seen to be spherical by observations with a telescope. The earth's shadow on the moon is circular during an eclipse. Aviators and ships have circumnavigated the earth. Photographs of the earth taken from great heights reveal a curvature in all directions.

The circumference of the earth as measured checks with the circumference calculated from the curvature obtained by measuring-instruments.

The circumference of the earth is about 24,800 miles. It is not strictly spherical but is slightly bulged (to the extent of 27 miles in diameter) at the equator. You will recall that Newton suggested that this bulging is due to centrifugal force produced by the rotation of the earth.

The mass of the earth is about 6×10^{21} tons.

The surface area is 197×10^6 square miles.

The Lithosphere Is Thought to Consist of a Dense Core of Metal Surrounded by a Thick Layer of Rock and a Relatively Thin Outside Crust.

The average density of the earth is 5.5 times that of water, although the average density of its crust, which is estimated to be about 60 miles thick, is only 2.7 times that of water. It thus appears that the center of the earth is composed of denser material than the crust.

Earthquake waves showing abrupt changes in speed at a depth of about 1800 miles suggest that the center of the earth, called the centrosphere, is a sphere of iron having a diameter of about 4400 miles. There is another abrupt change in the speed of earthquake waves at a depth of about 300 miles. One hypothesis is that the earth's crust consists of a layer of rock about 300 miles in depth and that there is a layer of sulfides of nickel and iron about 1500 miles in depth between the rocky crust and the metallic core. Tidal stresses of the sun and moon deform the earth as they would deform a sphere of steel rather than one of rock.

Examination of thousands of meteorites, as previously mentioned, shows that they consist of rocks, nickel, and iron, the iron and nickel being found in much larger quantities relative to their masses than are found in the earth's crust. According to the planetesimal theory, the earth and meteorites had a common origin. Where, then, is the

earth's allotment of iron and nickel? The present theory, as mentioned above, is that the iron and nickel form the core of the earth and that this core is a rigid solid, hot, perhaps, but not hot enough to be molten. You undoubtedly are thinking to yourself, "If the earth is solid inside then where does the molten lava of volcanoes come from?" This is a subject for a later section; but, in brief, it is now thought that volcanic activities are the result of local heat-producing disturbances.

STUDY QUESTIONS

1. Discuss man's attempts to explore the upper atmosphere.
2. Distinguish between the troposphere and the stratosphere.
3. What would you consider to be the advantages and disadvantages of stratosphere airplane travel?
4. What is the tropopause?
5. What is the probable nature of the centrosphere? Give the evidence for this conclusion.
6. Does lava flow out of cracks in the earth's crust from a molten interior?
7. What are the outstanding facts of importance to the geologist concerning the gaseous, liquid, and solid layers of the earth?
8. What is the composition of the dry atmosphere at sea level?
9. Discuss the reasons for concluding that the atmosphere may once have had a different composition from that which it has today.
10. Discuss the thickness of the atmosphere, stating how thick it is and giving the basis for this statement.
11. Why is it unlikely that man will ever penetrate the ocean depths?

UNIT III

SECTION 3

THE PRINCIPAL AGENCY IN THE GRADATION OF THE EARTH IS ITS ATMOSPHERE

Introduction.

The earth's atmosphere, when acted upon by the sun, produces the changes which the earth's surface is constantly undergoing. The sun not only produces changes in the temperature of the atmosphere that cause winds and rains, but it also heats water and thus causes it to evaporate into the atmosphere more rapidly. Water is the greatest agent of erosion. In the mountains, in the plains, or on the seashore, one can see water at work. Sometimes it works gradually, and sometimes it comes with the overwhelming force of floods. Running water removes soil from some places and deposits it at other places, sometimes where it is not wanted. Rain water erodes the surface of the earth as it runs off to the sea, and the snow and ice form vast storage reservoirs to maintain this run-off during periods of little precipitation. About one third of the rainfall evaporates, another third runs off to the ocean, and the last third soaks into the ground, where it begins its relentless work as ground water.

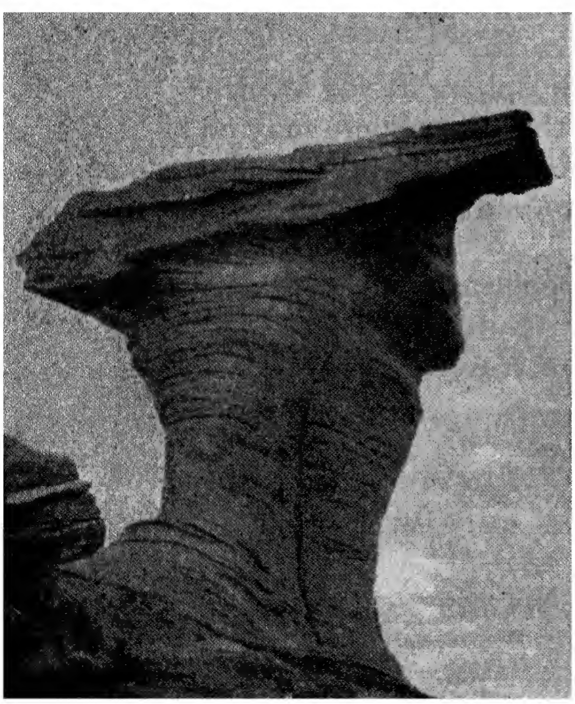


FIG. 35. A rock worn by wind-borne particles. (Courtesy of the U. S. Geol. Survey.)

The Atmosphere Acts on the Earth in Many Ways.

The unequal heating of the earth's surface causes movements in the atmosphere. A continuous flow of water from the mountains to the sea is assured by the water vapor that these winds carry. The winds are likewise responsible for the constant pounding of the waves on the shores of lakes and oceans.

The molecules of the gases that make up the atmosphere are so small that they produce little friction except when they are moving very fast. Strong winds seldom, if ever, wear down rocks without any abrasive agents. The great disintegrating power of winds is due largely to the particles of sand or dust which they carry.

Motor cars caught in a sand storm in the Mojave Desert have had all of the paint blasted from their bodies and the glass windshields and windows "frosted" by the flying sharp particles of sand. In only eleven years the telegraph wires of the Trans-Caspian Railway were worn to one half of their original diameter by wind-driven sands. This

FIG. 36. Dust storm, Johnson, Kansas, April 14, 1935.

action of wind is applied in the sandblast, which is used to cut designs into stone or wood or to clean off old stone buildings.

Winds produce many grotesque forms as they wear away the less resistant portions of rock formations. The beautifully colored rock formations in the Garden of the Gods at Colorado Springs were formed by wind erosion.

Winds also act as great transporting agents. Sometimes single wind storms in the southwest portion of the United States pick up a million tons of dust and scatter it over a dozen states. No one who lived in the Middle West during the drought of the summer of 1934 will forget the terrible dust storms.

In the United States, Europe, and especially in China, the wind has heaped up deposits of rock particles that are larger than clay but smaller than sand. Such detritus is called loess. The Yellow River in

China owes its color to the loess which it picks up as it carves its path through extensive plains of loess, all of which was probably blown from the Gobi desert.

Inasmuch as about three fourths of the earth's surface is covered by the ocean, it is to be surmised that tremendous quantities of land have been carried by the winds over the oceans, where it settled.

In the drier sections of the world the wind carries away the finer particles and leaves the sand, blowing it up into dunes. The wind is constantly changing the shape and size of the sand dunes, moving them from place to place, and overwhelming everything in their paths.

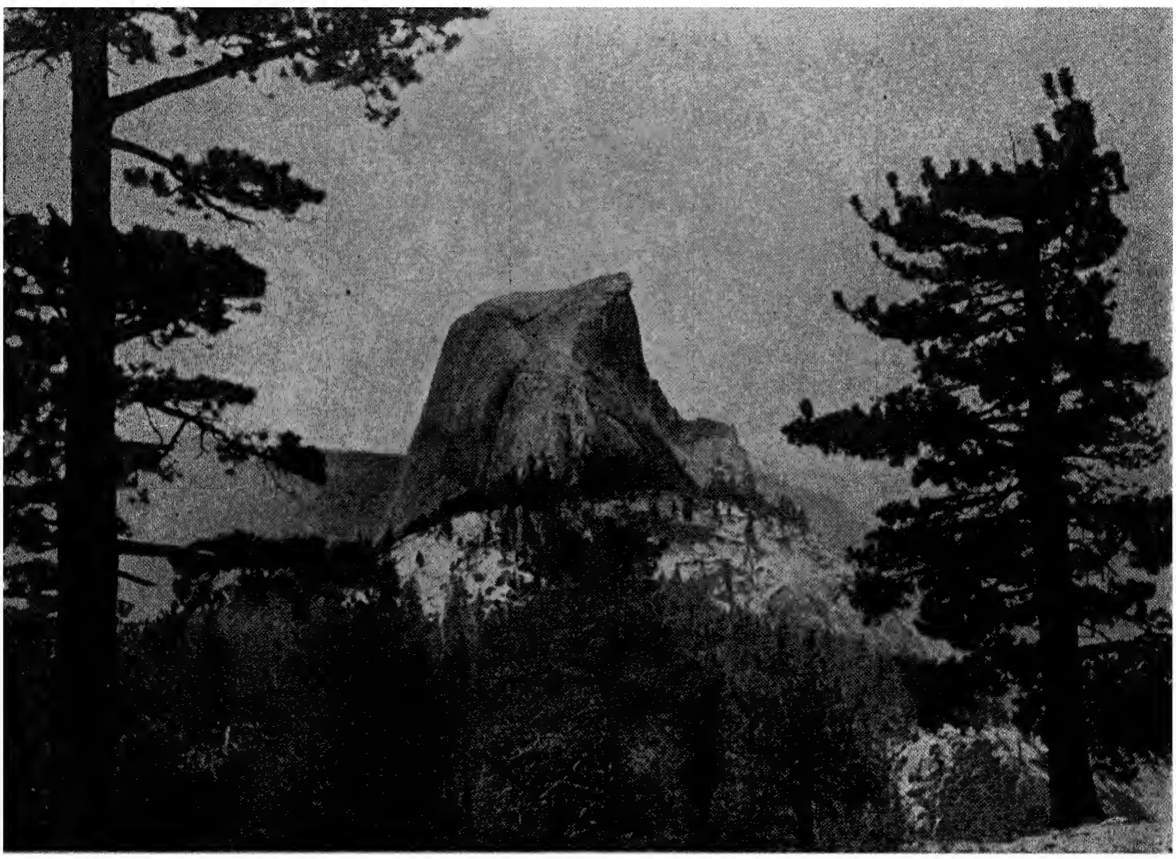


FIG. 37. Half Dome in Yosemite National Park, an example of exfoliation. (Courtesy of the U. S. Geol. Survey.)

Temperature Changes Bring About Disintegration of Rocks.

Inasmuch as rocks are poor conductors of heat, they heat unevenly and set up strains which result in cracks, just as glassware cracks when it is placed under such a strain. Water which gathers in the cracks of rocks expands when it freezes and thus splits the rocks apart.

"Exfoliation" is the name given to the process in which sharp edges and corners of rocks are rounded off and layer after layer peels off to form rounded domes. Exfoliation is thought to be caused by chemical action, weathering, and expansion due to the decreased pressure resulting from removal of heavy overlying loads.

Gravity Acts as a Transporting Agent.

Gravity constantly moves disintegrated portions of rocks to leave fresh surfaces to be acted upon by all the forces of erosion. Loosened stones are disturbed by the wind, animals, plant growth, snow, and water and fall to the base of a cliff or mountain to form *talus* slopes. These rocks, which are thus constantly exposed, weather more rapidly than those which are protected by layers of disintegrated and decomposed rock in the valleys. When the soil is loosened by rains, landslides often occur, sometimes with very disastrous results.

Plants Are Disintegrating Agents.

The seeds of plants may lodge in small crevices in rocks, whence they send out roots whose gradual growth in diameter exerts pressures of hundreds of pounds per square inch. Many large rocks are broken by this means.

Many Chemical Changes Bring About Decomposition of Rocks.

Water, charged with carbon dioxide gas, dissolves limestone to form caves. Water may dissolve many other substances, such as sulfur dioxide, and carry them to otherwise insoluble rocks, which it is thus able to decompose through the action of these dissolved substances on the rock to produce soluble substances, which are then leached out. Underground gases and gases from volcanoes thus render underground waters very active, especially where high pressures cause very large quantities of these gases to dissolve in water.

On the surface, the ever constant films of water contain oxygen and carbon dioxide dissolved from the atmosphere. In the presence of water, a great many rocks are acted upon by these two substances to form new, more soluble, or mechanically weaker materials.

Water itself is an important decomposing agent; it combines with many rock materials, causing them to swell and decrease in strength or to become more soluble.

Running Water Is the Most Active Eroding Agent.

The erosive power of running water depends upon its velocity; it is increased about sixty-four times for each time the velocity is doubled. The tremendous power of the water to plow out debris and transport it can be seen after a cloudburst has occurred on a freshly plowed hillside. Such dry spots as Death Valley seldom have rain, so that there is little vegetation to prevent the ravages of the infrequent cloudbursts, which wash out deep ravines and obliterate roadbeds

within a few hours. Less rapid currents of water are slower in their action but no less effective in the long run. They constantly round off the boulders and rocks as they jostle them about against each other and against the rocky canyon walls and transport the lighter particles thus formed farther down stream. The Mississippi River carries a million tons of silt and sand to the Gulf of Mexico every twenty-four hours. Large deltas are formed by such rivers as the Mississippi, the Nile, and the Yangtze as they dump their debris into the sea. Valleys like the great Sacramento and San Joaquin River valleys in California have been filled to a depth of as much as 1500 feet by the sand and silt washed down from the nearby mountains. Huge gashes have been cut into high plateaus by swiftly flowing rivers such as the Colorado River. The Colorado River Canyon is 214 miles long, from 8 to 12 miles wide, and over a mile deep.

At the foot of mountains the debris resulting from the disintegration of the rocky materials is carried out by the water into the valleys, forming large delta-like fans. As time passes, the mountains are gradually worn down, and these fans creep up the canyons until the mountains become level plains.

Eventually these deposits become cemented together by chemical action of the water and its contents with the sediments, and new layers of stratified rock come into being.

Oceans and Lakes Disintegrate Their Shore Lines.

Oceans constantly pound their way into the rocky shores, wearing down the rocks to form the beach sands and to form still smaller particles which are carried farther out to form shallow submarine plains. Later these plains may be elevated several thousand feet, and the rivers commence once more the eroding process. At other times the plains near the sea are lowered so that the water covers them, forming large bays and estuaries.

While as a rule the waves in lakes are smaller than those in the oceans and therefore subject their shore lines to a more gentle pounding, on the other hand, lakes in cold climates freeze over, and the expanding ice grinds the shore lines.

Underground Waters Contribute Largely to the Disintegration of Rocks.

Underground waters seep through porous layers and into cracks, dissolving out soluble substances, and eventually re-emerge as springs to feed the rivers. Billions of tons of dissolved matter, nearly a quarter of the total material transported by rivers, are thus carried in solution to the oceans every year.

Slichter, consulting engineer of the United States Geological Survey, has estimated that the amount of ground water is nearly one-third as great as that in the oceans.

Generally, the ground waters settle on an impervious layer of rock and reach a level called the water table, sometimes near the surface and at other times quite deep. When streams cut below these water tables, springs appear along the banks. Water seeps into wells when they are driven below the water table. Sometimes portions of land lie below the water table, and a swamp or lake results.

Ground waters may move through the soil or rocks very slowly, sometimes only a few hundred feet per year. These waters frequently

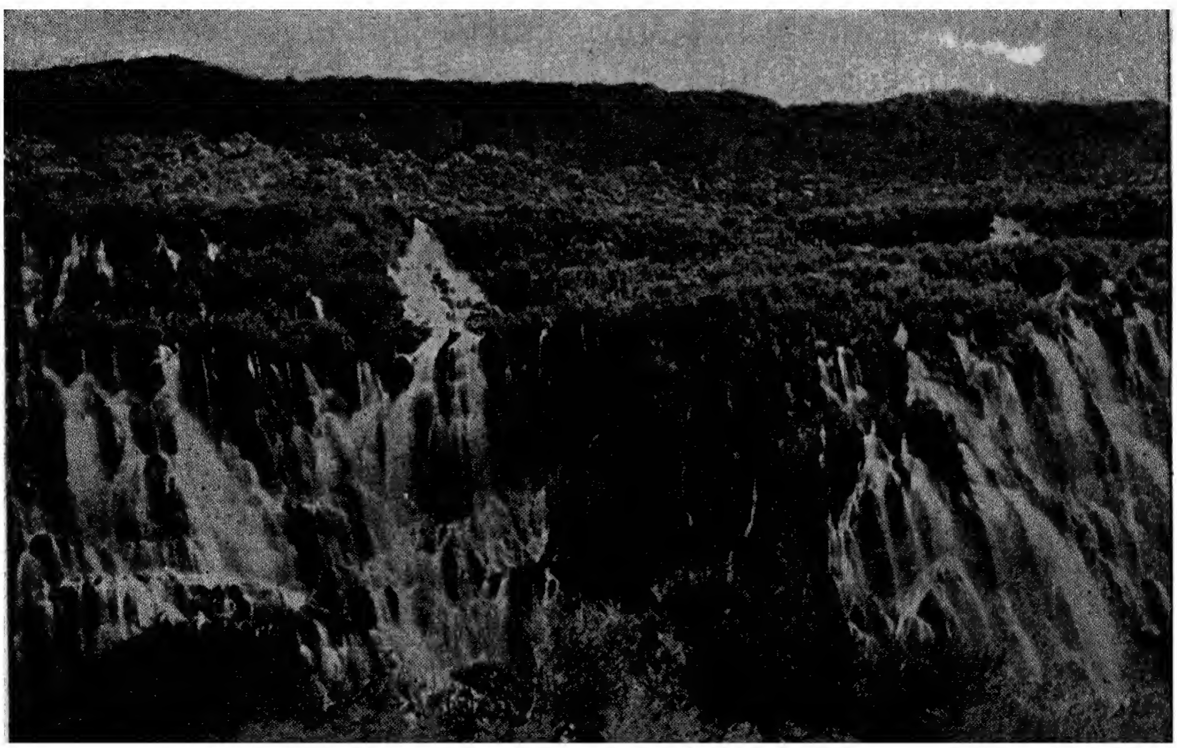


FIG. 38. Thousand Springs, Snake River Canyon, Idaho. Outlet for ground-water flowing through porous lava. (From Reeds, Chester A., *The Earth*, published by the University Society.)

become charged with carbon dioxide, which gives them the solvent action necessary to dissolve limestone and form such huge series of caves as the Carlsbad Caverns in New Mexico and the Mammoth Cave in Kentucky, which extend scores of miles underground.

Sometimes ground waters collect in fissures between rocks and pour out as veritable rivers. Artesian wells are produced when pipes are sunk into ground water that is under pressure. Occasionally the pressure of the steam formed in the lower portions of fissures causes the water to shoot upwards suddenly as a geyser. This action of geysers may occur regularly, as in the case of Old Faithful in Yellowstone National Park, or irregularly, as in the case of Eaimangu in New

Zealand, which has spouted streams of mud and water as high as 1500 feet at the most unexpected times.

Springs carry many kinds of dissolved substances from under ground. Some spring waters contain sulfur compounds, carbon dioxide, iron compounds, soda, epsom salts, borax, acids, alkalies, rare gases, or even poisonous salts in solution. The hot waters from springs often precipitate their mineral freightage when they reach the surface and are cooled, thus forming interesting deposits like those found in Yellowstone National Park. At San Filippo, Sicily, a hill about 250 feet high and over a mile long was formed in this manner; it continues to grow at the astonishing rate of three feet per year.

Much of the mineral matter dissolved by ground waters at one place is deposited at another place; thus cracks and pores are filled with concentrations of certain minerals.

Glaciers Are Powerful Agents of Degradation.

There have been periods in the earth's history when large portions of the surface were covered with ice. Glaciers a mile deep once flowed over two million square miles of Europe. Similar glaciers spread over four million square miles of North America, going over mountain ranges such as the Adirondacks in New York like a tractor and rounding them off to produce the typical New England scenery. These huge masses of ice gouged out the hollows now filled with water to make the numerous lakes of Canada and carried the resulting debris to the northern part of the United States, where deposits several hundred feet deep were left.

During the past million years at least one fifth of the land area of the earth has been under ice. On the other hand, large coal beds in Alaska point to the former tropical climate there and suggest that there have been periods when much less ice existed.

The earth is now recovering from what appears to have been its greatest ice age. Antarctica and Greenland are still buried under sheets of ice. Many mountains still harbor extensive glaciers, while ice flows and icebergs abound in northern and southern seas.

Mountain glaciers are rivers of ice; some, many hundred feet thick, move a few inches or feet per day, grinding rocks in their path with their tremendous frictional force. This force is increased by rocks, ranging in size from the smallest pebbles to boulders weighing many tons, which have become incorporated into the bottom of the glacier to make a very effective grinding surface.

Mountain glaciers are formed from the winter snows that fail to melt completely in the summer and pile up year after year, gradually

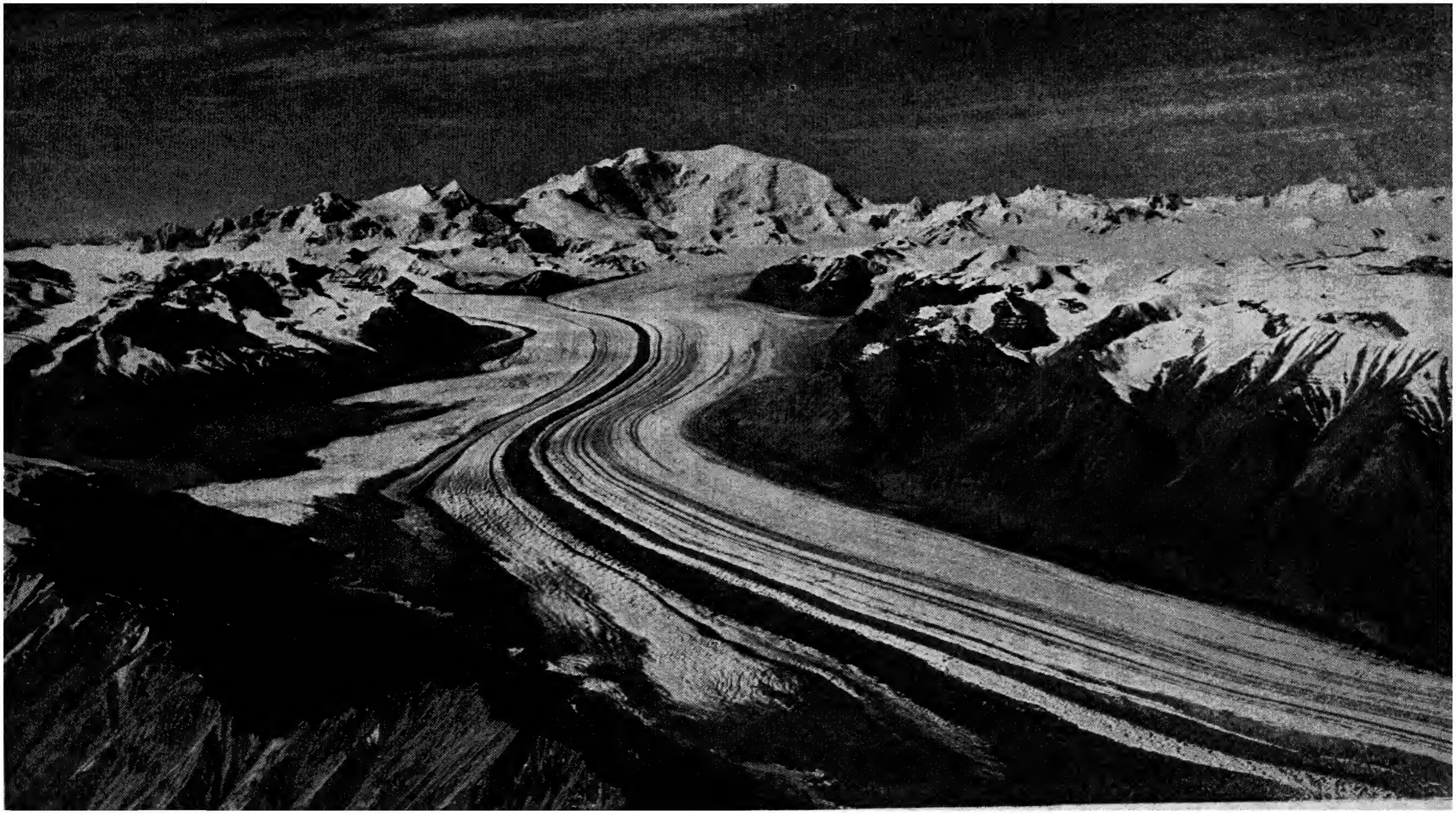


FIG. 39. Nabesna Glacier and Mt. Blackburn (16,140 feet) in the Wrangell Range, Alaska. (Courtesy of the New England Museum of Natural History.)

changing to ice as a result of the heat of the sun and pressure of the accumulating mass.

Glaciers produce typical amphitheater-like or U-shaped valleys, called "cirques." The best evidences of glaciation, however, are the scratches that are left on the surfaces of rocks.

The last ice age was in full retreat about 25,000 years ago. Evidence of previous ice ages, many millions of years ago, both in the southern and northern hemispheres, have been found in some of our older rocks.

During the Pleistocene age, great glaciers spread over Europe and North America, retreating and returning again at least four times. Great and relatively rapid changes must have taken place as plants and animals tried to adjust themselves to these changing conditions. Perhaps this period marked the dawn of mankind.

Oceans Unceasingly Wear Away Their Shores.

Two types of motion in the oceans are responsible for their erosive action along a million miles of shore. The first of these, the tides, has little effect except where the waters rush into narrow channels, sometimes piling up as high as 50 feet. The constant hammering of the waves is the main means by which the oceans gradually change the shore lines of the continents.

An example of marine erosion is seen in the decrease in the size of the Island of Heligoland at the mouth of the Elbe in the North Sea. Its circumference was reduced from 120 miles in 800 A.D. to 45 miles in 1300 A.D.; by 1900 it was only 3 miles, and the island would probably have soon entirely disappeared if the German Government had not reinforced it with a wall of concrete, so as to preserve it for a naval base.

STUDY QUESTIONS

1. What would the surface of the earth be like if it had no atmosphere?
2. Show how the atmosphere is the ultimate cause of the gradation of the earth.
3. What is the most active agent of erosion?
4. Explain the formation of caves such as the Carlsbad Caverns.
5. Explain the formation of such U-shaped valleys as Yosemite Valley.
6. How do glaciers bring about erosion?
7. Explain the existence of swamps.
8. Why is the Dead Sea more saline than the Great Salt Lake?
9. Explain how rivers change the landscape.
10. Explain the formation of lakes.
11. Do you think that the northern part of North America will ever be covered by glaciers again?
12. Give a possible explanation of hot springs and geysers.
13. List the most important weathering agents.

14. What are the most important types of chemical changes that are involved in weathering?
15. Name the outstanding scenic spots in the United States and state the most important agents of erosion which have been responsible for them.
16. Explain how temperature changes can bring about weathering.
17 List the various agents of erosion under the three topics: disintegration, decomposition, and transportation.
18. Mention four different ways in which water brings about erosion.
19. Why are the desert winds so effective in erosion?

UNIT III

SECTION 4

THE CHARACTERISTIC FEATURES OF THE LANDSCAPE BECOME MORE INTERESTING WHEN THEIR HISTORY IS UNDERSTOOD

Introduction.

There are few people who do not enjoy a vacation in the mountains or at the seashore, or a motor trip through our national parks. The enjoyment of such a communion with nature is increased for many people when they can understand even in a small way the origin of the various topographic features which they see.

Most of the Characteristic Features of Any Landscape Are Caused by the Gradational Action of Running Water.

Every river and every canyon or river valley started as a mere trickle in a small depression in the soil, which gradually developed into a gully. As the gully deepened, more water flowed into it, and soon a stream was formed. Many small rivulets formed at first; but the majority of these were destroyed by the more favored ones, which grew larger at the expense of the smaller ones, until there were only two or three ravines where there had formerly been hundreds of small rivulets. (There is much competition among young streams, and the largest and swiftest ones are those which win out.) The stream used its newly developed young strength to wear down the surface to form gulches and ravines, and the harder it worked the faster it grew and the larger it became, until in its husky youth it cut huge V-shaped valleys, leaving sharp shoulders and narrow bottoms. The Colorado River is a rampant young river that has cut the Grand Canyon, and up until the time when man hastened his maturity period, it went on reckless sprees of devastating floods. The aging of rivers is a slowing-down process, in which the rate of flow of the water is gradually decreased as the high places are worn down and the low places are filled up. In order artificially to age the Colorado River, a low place in the river was filled by a dam, Boulder Dam, thus decreasing the rate of flow of the river to form a lake.

Rapids and falls are characteristic of young rivers, but as rivers approach maturity the down-cutting decreases, and lateral cutting increases, U-shaped valleys are formed, the valley floors become considerably wider than the stream itself, and many tributaries develop.

When rivers reach old age, they flow very slowly as they meander and squirm through wide valleys which have been filled up by sediments carried down in their more youthful days. The old rivers are large, and the number of tributaries is reduced.

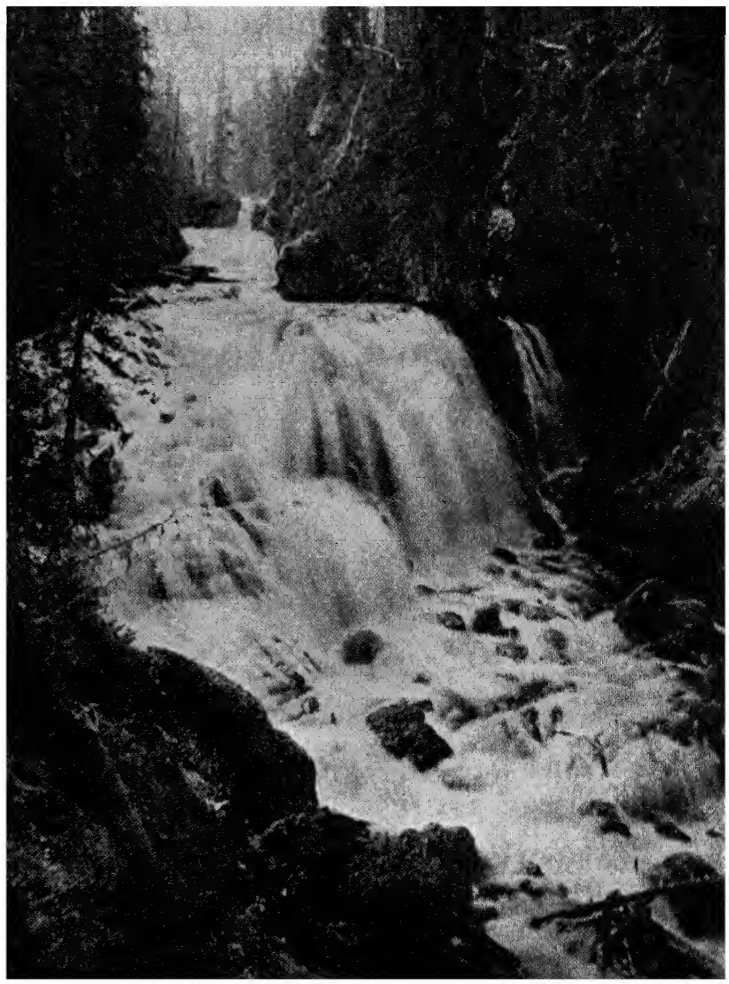


FIG. 40. A young stream. (Courtesy of the U. S. Geol. Survey.)

The growth of a stream resembles the growth of a tree. A young sapling may die during a drought which would not destroy a larger tree which has roots that extend deeper into the ground. Similarly, a young stream may dry up during the summer; but eventually it cuts down to the water table, and the ground-water reservoirs augment the direct run-off from rains. Such streams become permanent.

Sometimes old streams experience a second youth as the areas through which they flow are gradually lifted up and thus form steeper slopes and swift-flowing streams because the hard rocks are lifted up more rapidly than the streams can wear them away.

Other streams cut down the rising mountains as fast as they form, producing tremendous gorges; the Columbia River cut a seventy-mile path right through the Cascade Mountains, which were uplifted long after the Columbia River established its course. Such rivers are called *antecedent* rivers.

The mature river valley resembles the great spreading branches and foliage of a large shade tree. In the lower portion of the valley, where the swiftness of the stream decreases, the silt and soil particles settle over the beds of gravel and sand deposited when it was a young rushing

stream. This filling-up of the valley gradually proceeds upstream. The valley is then further widened as the river forms S-curves, and during flood periods large amounts of silt are deposited over the valley floor, and the stream may start a new course that continues to widen the valley still more. The vast valley of the Mississippi River is an example of the valley of an old river.

The youth or maturity of a given region can be told by observing the rivers and valleys. A new uplift will have few valleys, and those that exist will be canyonlike. Older topography will be characterized

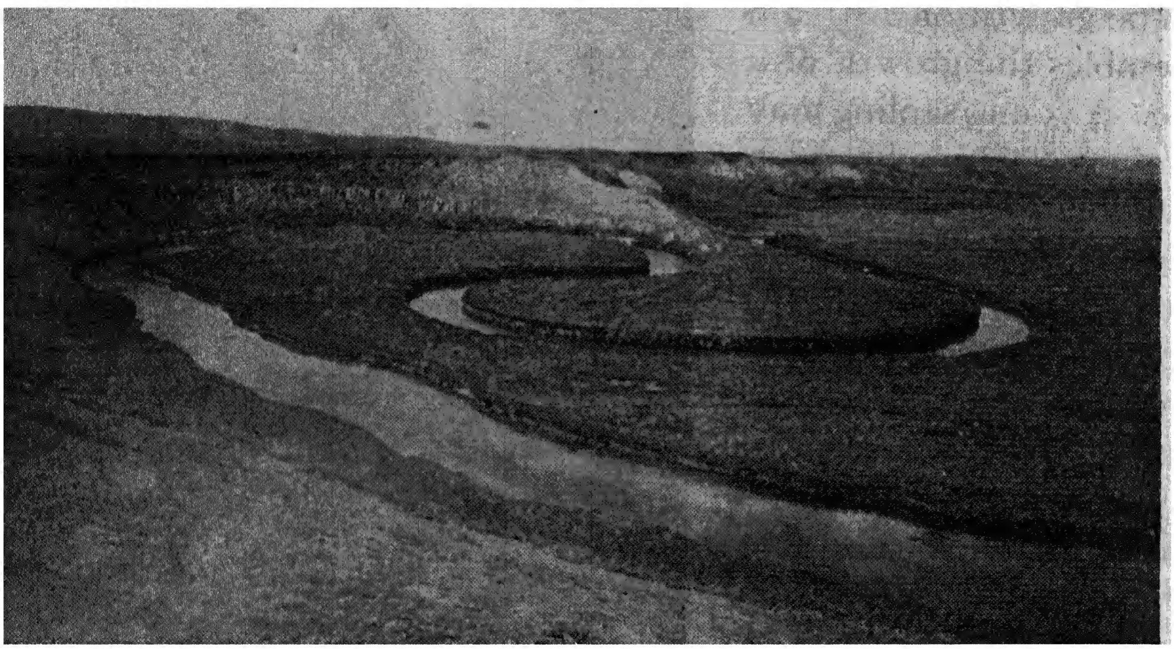


FIG. 41. The meanders of an old river. (Courtesy of the U. S. Geol. Survey.)

by a fretwork of ridges and valleys. These ridges gradually become gentler hillsides, and eventually the region becomes quite level. The present Sierra Nevadas or the Grand Tetons in the Yellowstone National Park are young mountains. The Appalachian Mountains are much older, while the rolling country of the great central portion of the United States represents old age in so far as the rivers and general topography are concerned.

The Unequal Hardness of Rock Strata Also Contributes Characteristic Features to the Landscape.

The different rock strata were formed under varying conditions. Sometimes they were under branches of the ocean; at other times they were covered by glaciers, perhaps. They may have been subjected to tremendous pressures and temperatures as they were bent, twisted, folded, and faulted during the wrinkling of the earth's crust as a result of unequal pressures. The differences in the nature of the materials, such as are illustrated in sandstone, limestone, and granite, and the

difference in the treatment which they received after their formation resulted in differences in hardness, *i.e.*, resistance to erosion and weathering.

Terraces, buttes, mesas, tablelands, rapids, and waterfalls result from differences in the hardness of flat-lying strata. The "Cave of the Winds" was carved in soft rock strata underlying harder strata by the rushing waters of Niagara Falls. Niagara Falls is possible only because the water at the top does not come from a steep slope, which would enable it to pick up abrasive materials that would soon wear away the falls, and also because the upper strata of rock are harder than those immediately under them. Niagara Falls recedes at a rate of about 4½ feet a year, the chief action being that of the dissolving away of the softer strata, thus leaving the upper strata without support to withstand the weight of the water which rushes over it; the result is that portions of the hard upper layer break off from time to time.

Unequal hardness in tilted strata causes water gaps where rivers work their way through softer strata in mountains; ridges of hard strata are called *hogbacks*.

Badlands Are Characteristic of Old Topography in Arid Regions.

Badlands are often found in arid regions in soft deposits of clay or shale characteristic of old topography. In these regions it does not rain often; but when the rains do come they usually arrive in the form of cloudbursts that wear deep gullies into the land, where they remain until another cloudburst adds "insult to injury." There are few gentle rains to level off these gullies gradually between cloudbursts. Badlands are typical of old topography in arid regions.

Lakes Have Comparatively Short Lives.

Many lakes occupy low spots on the land that have resulted from sinking of certain areas under the pressure of glaciers, as in the case of the Great Lakes of North America, or from the water's carving action, as in the case of oxbow lakes in the wide valleys of old rivers. Lakes may be formed by glaciers whose forward walls have melted in a valley as fast as they have progressed down the valley, with the result that the terminus of the glacier has remained in the same place and gradually piled up large heaps of rocks and detritus, which dammed up the valley to form a lake.

Changes in river courses, underground caves, and other changes in the earth's surface may produce lakes. Lakes are found in elevations ranging from that of Lake Titicaca in Peru (12,500 feet above sea level) to that of the Dead Sea in Palestine (1300 feet below sea level). The

majority of lakes are relatively shallow, although there are notably deep lakes such as Crater Lake (2000 feet deep) and Lake Baikal in Siberia (5618 feet deep). Lakes usually have outlets, so that the soluble salts do not accumulate. The insoluble suspended matter settles out from the quiet waters of lakes, gradually filling them, until they eventually turn into swamps.

Many lakes which have been formed in arid districts have no outlets, and salts accumulate in them just as they do in the oceans, except that the more rapid evaporation in these lakes produces more highly concentrated salt solutions.

Ocean Shore Lines Change As the Land Sinks or Rises.

It is unlikely that ocean beds have ever risen to form continents, and there is no evidence that the continents have ever been completely covered by the deep ocean. The sedimentary rock formations were probably produced for the most part in great arms of the sea (like Hudson Bay and the Yellow Sea), lakes, and other shallow waterways rather than in great ocean depths.

Constantly the ocean wears down the shore at one place and produces beaches and bars at other places, and about the time that the ocean seems to be making real headway into the land areas, they are elevated by internal disturbances (to be discussed later), causing the formation of new shore lines. The coast in the far eastern part of the United States has been gradually sinking, producing channels and islands where rivers and hills once prevailed. On the Pacific coast of the United States, on the other hand, the wave-cut terraces of the Southern California coast show that there has been a recent gradual uplift amounting to as much as 1500 feet.

The continents are surrounded by shelves varying in width from 5 to 300 miles and averaging about 75 miles. These are smooth, gently sloping plains, whose final depth is about 600 feet. At the outer edges the underwater platforms give way rapidly to the deep ocean basins. These continental ledges catch most of the sediment carried from the land into the ocean.

A mountainous ridge almost 10,000 feet above the adjoining basins runs down the middle of the Atlantic Ocean, extending 8000 miles south from Iceland.

If the oceans were to be lowered only 600 feet by the formation of huge sheets of ice, Ireland would be joined to England and England would become a part of the mainland of Europe. North America would be connected with Asia by a strip 1500 miles in width. New Guinea would become a part of Australia.

The discovery of submarine canyons, which closely resemble those cut by rivers on land, suggests that these canyons were actually cut in the present ocean bottom at some previous time when there was so much less water in the oceans than at present that these portions of the ocean bottom were dry land. According to one theory, the ocean may have been lowered as much as 3000 feet during the ice ages, in which the glaciers may have been as thick as 10 miles.

The average height of all of the land on the earth's surface is 2300 feet above sea level, while the average depth of the oceans is about

FIG. 42. View of Yosemite Valley from Inspiration Point. Note Bridalveil Falls. This is a typical glacial valley. (Courtesy of the U. S. Dept. of the Interior.)

13,000 feet below sea level. The summit of the highest mountain, Mount Everest (29,141), is only about 12 miles higher than the lowest spot in the oceans, Swire Deep, east of the Philippines (35,410 feet). Given enough time, erosion alone would carry all the land areas into the ocean, and the whole earth would be covered with water. If all the land were reduced to a common level, it would be covered by the ocean to a depth of two miles. As it is, the oceans cover 70.8 per cent of the earth's surface to an average depth of 13,000 feet, as mentioned above. In spite of this, it is probable that the land and water areas have not greatly changed during the past few millions of years.

Glaciers Leave Typical Topographical Features.

When debris accumulates along the sides of glaciers, *lateral moraines*, or ridges, are formed. Gentle rolling plains produced by glaciers dropping their loads are called *ground moraines*. The material is composed of some boulders and considerable clay.

Glaciers not only carry debris along on their surfaces but also have rocks frozen into them that add to their grinding power. As glaciers slowly move, a few feet per year, perhaps, and a little more rapidly at the top and in the center than at the bottom and along the edges, the bedrock surfaces are polished, scratched, and grooved, while angular boulders are smoothed.

When glaciers move down young valleys, they widen and deepen them, polishing and grooving the valley walls, and change their shape from a V to a U. Yosemite Valley is a glacial valley.

When the huge glaciers of the five ice ages covered parts of North America, they rounded off the mountains and hills to form *drumloids*.

An elliptical hill of glacial debris formed beneath an ice sheet is called a *drumlin*.

STUDY QUESTIONS

1. Compare a glacier with a river.
2. How can one recognize glaciated topography?
3. Give the chief characteristics of young rivers and account for them.
4. What are the characteristics of the aging of rivers?
5. How can one tell the age of a given mountain range?
6. What types of scenery are caused by the unequal hardness of rocks?
7. Where are badlands found?
8. Account for the typical badland topography at Zabriskie's Point in Death Valley.
9. How are rivers rejuvenated?
10. What is an antecedent river? Give an example.
11. What happens to shore lines as land areas sink and lift?

UNIT III

SECTION 5

DIASTROPHISM AND VULCANISM TEND TO REVERSE THE RESULTS OF DEGRADATION

> That part of the surface of any heavy body will become more distant from the center of its gravity which becomes of greater lightness. The earth therefore, the element by which the rivers carry away the slopes of mountains and bear them to the sea, is the place from which such gravity is removed; it will make itself lighter and in consequence will make itself more remote from the center of gravity of the earth, that is from the center of gravity of the universe which is always concentric with the center of gravity of the earth. . . . The summits of the mountains in course of time rise continually. — Leonardo Da Vinci.

Introduction.

It is reasonable to conclude that the agents of gradation are capable of destroying all of the earth's land areas if given time. Furthermore, there is every reason to believe that more than enough time has elapsed to have brought about complete gradation of the lithosphere. The fact that land areas exist today indicates that there are forces which tend to balance the forces of gradation.

Diastrophism and vulcanism are the forces which lift up land areas, and they are produced by the same changes that bring about gradation. There is no reason to think that these balancing forces will not continue as long as the earth has an atmosphere, and therefore as long as erosion continues, because it is erosion itself that disturbs a condition of equilibrium that exists and thus brings these compensating forces into action. It is fascinating to study how erosion thus seems to defeat its own ends.

Diastrophism refers to all movements of the outer shell of the earth. Vulcanism refers to all phenomena that are connected with molten rock material and its movements; the term is derived from Vulcanus, the Roman god of fire, who was supposed to dwell in a volcano.

Earthquakes Are the Result of Tremendous Changes in the Earth's Surface.

During the past fifty years, the world has known many disastrous earthquakes. Japan has experienced three such earthquakes — in

1891, 1896, and 1923. The last earthquake killed more than 140,000 people and destroyed property worth billions of dollars.

California has had four great earthquakes during the same period. San Francisco was all but destroyed by the fire following the great earthquake in 1906, and Santa Barbara and Long Beach experienced considerable damage in 1925 and 1933. The Imperial Valley experienced, in 1940, the fifth most destructive earthquake recorded in the United States. Charleston, South Carolina, experienced a disastrous earthquake in 1886, and Helena, Montana, experienced one in 1935.

Nearly a hundred thousand people were killed in Messina in Sicily by an earthquake that occurred in 1908.

During this same fifty-year period similar great disastrous earthquakes have occurred in India, China, the West Indies, and South America.

Earthquakes, small or large, are occurring at some place on the earth's surface all the time; and they have been taking place since history began to be recorded. There are probably about 150 large earthquakes a year, although very few of them make the front pages of newspapers because most of them occur under the sea. It has been estimated from the records that 13,000,000 people have lost their lives in earthquakes during the past 4000 years.

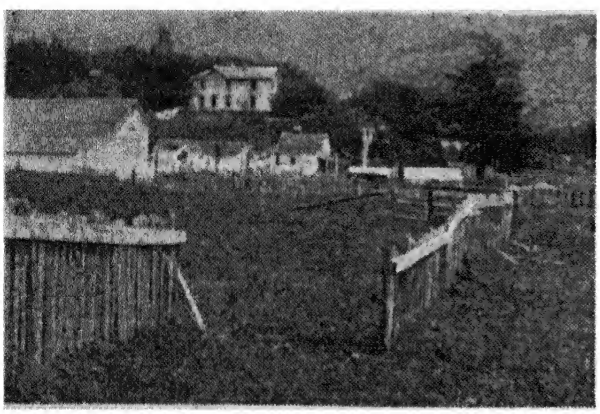


FIG. 43. A fence shifted by an earthquake. (Courtesy of the U. S. Geol. Survey.)

It is only within the past few decades that man has learned the nature and cause of earthquakes. The earthquake is now known to be a vibration of the earth's crust. Such vibrations could be produced by friction or jarring, but this would be insufficient to cause anything but minor tremors. The majority of earthquakes are caused by the sudden slipping along fractures of portions of the earth's crust or by the fractures themselves. Rocks are somewhat elastic under the stress of great pressures and bend slowly for centuries until they reach the breaking point.

Sometimes great blocks of material, separated from others by cracks, are elevated or lowered, producing faults. In 1899 a block of forest on the Pacific coast of the United States was submerged into the sea, whereas a neighboring block was elevated forty-seven feet. In the great earthquake of 1811–1812 in the Mississippi Valley, a lake twenty-four miles long was formed by the subsidence of a section of land in

Tennessee. The great San Andreas fault, six hundred miles long, was the location of the shifting in the earth's surface which produced the earthquake which caused the San Francisco fire.

The main stresses in the earth's surface today lie along fractures bordering the Pacific Ocean and a path that reaches through the Mediterranean, the Himalayas, and the East Indies.

The earthquakes produced by faults, called "tectonic earthquakes," may shake entire continents. Less extensive earthquakes may be produced by the explosive eruption of volcanoes. Tokachi caused great damage in the nearby town of Menegama in Japan as a result of the earthquake accompanying the explosion of this volcano in 1925.

A few minor earthquakes have been produced by the collapse of the roofs of large underground caverns, landslides in mountain regions, or the slumping on delta slopes.

The Seismograph Is One of the Geologist's Most Useful Instruments.

The seismograph is a delicately adjusted instrument extremely sensitive to vibrations, whose amplitude it records.

There are about 350 seismographs located at various stations on the earth's surface to record earthquakes. The seismograph enables the scientist to determine the exact location of the larger earthquakes, even when their centers are thousands of miles away. Earthquake vibrations are transmitted through rock by different types of wave motion. The majority of earthquakes originate in the earth's outer crust, but the resulting vibrations travel throughout the globe. Some travel around the surface, while others travel to the center where they are deflected by the dense cores. The time intervals between the arrivals of the different waves are noted at three different stations. Inasmuch as these time intervals are determined by the distance from the earthquake center, the earthquake center may thus be precisely located as shown in Fig. 44.

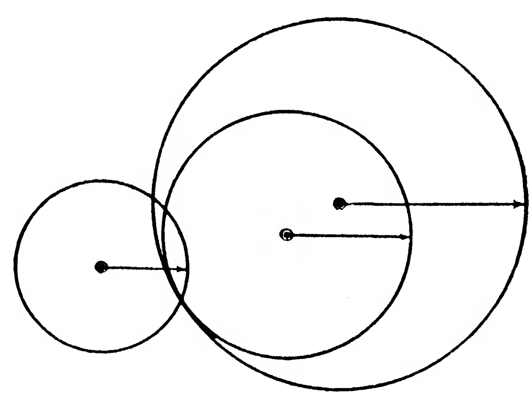


FIG. 44. Three observatories cooperate in locating an earthquake. A circle is drawn around each station as a center, with a radius equal to the estimated distance to the earthquake. The intersection of the three circles is the desired location.

There are two general types of seismographs in common use. The first consists of a heavy pendulum, which holds a delicate penpoint against a moving sheet of smoked paper and makes waves in the lines thus formed according to the amplitude of the vibrations. The second

type of instrument employs a small mirror mounted on a balanced weight, which causes a beam of light to move on a moving piece of photographic paper. The problem of the high cost of developing the photographic paper has recently been eliminated by the use of a photoelectric cell,[1] which sets up a fluctuating electric current as the beam of light flickers across it. This current, amplified by a vacuum-tube hookup, drives a pen which records the wave on a plain white paper.

The essential part of the seismograph is like a pendulum, the bob of which tends to remain stationary in space, while everything attached to it moves. It is impossible to attach the pendulum in such a way that it does not move to a certain extent with the earth, but this motion may be corrected so as to obtain the true motion of the earth relative to it.

It has been found that the vibrations produced by earthquakes pass through the center of the earth. The rate at which vibrations pass through different media is quite well known; and from this information it is concluded that, if the center of the earth is a molten liquid, these vibrations would travel much less rapidly than they actually do travel.

Data obtained with the seismograph and other lines of evidence suggest that the earth has an outer layer of soil and rock about 37 miles thick. Beneath this layer there is thought to be a layer of compounds of iron, magnesium, and silicon about 950 miles thick. Below this there is another similar layer about 875 miles thick, in which the iron content increases with the depth. The center of the earth is thought to consist of a core of iron and nickel, which accounts for its magnetism. The other elements are found throughout these layers in relatively insignificant quantities. If these ideas are correct, it seems quite possible that the earth may have been in a molten condition at one time, these substances being separated in layers in accordance with their densities.

Earthquakes are recorded by seismographic stations throughout the world. The deformation of the earth under the influence of stresses which develop within it frequently takes the form of sudden fractures. Displacements at the surface are produced by these fractures, which start vibrations that spread throughout the earth. Inasmuch as any earthquake is made up of three linear displacements along directions at right angles to each other, a fully equipped observing station requires three seismographs, set to read the north-south, east-west, and vertical components of the earthquake. A rough estimate of the position of the earthquake origin can be obtained by stations thus equipped, without the use of records from other stations.

Although the primary causes of earthquakes lie within the earth, it

[1] This topic will be studied in a later unit.

is quite possible that the actual time of occurrence is determined by such external factors as the change in pressure due to annual and daily changes in atmospheric pressure. Earthquakes occur more frequently during the night than the day and more frequently in winter than in summer. Years of many sunspots show a greater number of earthquakes than usual. Microseisms, or very small oscillations, are thought to be produced by storms; they are much more frequent in winter than in summer.

Mountain Ranges Have Been Formed by Slow Uplifts of the Earth's Surface.

The forces which have caused earthquakes have been producing very slow changes in the earth's surface. Some portions of the earth's surface are being elevated gradually. The Italian island of Palmarola has risen more than 200 feet since 1822. The northern part of the Scandinavian Peninsula has been rising for several thousand years. Shore lines have been raised 1000 feet above the sea in northern Sweden. An elevation is taking place in the region of the Great Lakes along the Canadian border, where the present elevations rise 600 or 700 feet above former levels.

On the other hand, the eastern coast of the United States is sinking, as is also the northern coast of France. The Bermuda Islands have sunk to the extent that a former area of 576 square miles has been reduced to 20 square miles.

Some mountains are wholly volcanic in origin, while others, like the Catskills, were formed by erosion of high plateaus. The Black Hills of South Dakota were formed by the erosion of a huge dome upthrust 9000 feet by a lava intrusion.

The great mountain ranges of the world, like the Alps, the Himalayas, the Rockies, and the Sierra Nevadas, were formed by faulting and folding. These mountain ranges represent rock layers produced by sedimentation in shallow ocean beds to a depth of 25,000 to 30,000 feet, which have been forced upward in the form of mighty folds. Inasmuch as the continental shelves are not over 600 feet deep, a layer of sedimentary rock 30,000 feet thick could be formed only by the gradual sinking of these shallow basins as they became filled with sediment. At the same time the neighboring land must have been rising gradually to provide sufficient material for the tremendous amount of erosion necessary to form such huge amounts of sediment. When the Appalachian range was folded, the circumference of the earth was decreased about 100 miles or more, and it was decreased perhaps twice as much when the Alps were formed.

The thick layers of sedimentary rocks could only have been formed in shallow basins near the shores of large land areas which were undergoing intensive erosion. Today similar layers of sediment are being deposited by the great rivers of China in large basins where new mountain ranges will probably be born in the far distant future. The motions of the earth's crust, by which these basins were lowered and neighboring land was elevated, and finally by which great mountain ranges were elevated from these basins, are explained by the modern theory of *isostasy*.

Erosion Distributes Weight and Pressure Unevenly and Thus Produces Isostatic Readjustments Which Tend to Offset Its Leveling Processes.

Erosion carries tremendous quantities of material from one place to another, decreasing the weight over one area and increasing the weight over other areas. The density of the rocks under the oceans is greater than that in the land areas, as a rule, while the density of the substances carried into the oceans is greater than that of the substances left undissolved on land. The total effect of these various factors is to cause the portions of the earth under the oceans to be heavier than the land areas. The fact that the surface of the earth under the oceans is composed of heavier material than that on land has been shown by measurements with a pendulum, which has a slightly shorter period of oscillation over the ocean basins than over land areas.

The heavier lowlands reach a state of equilibrium with the lighter highlands; but erosion unbalances the equilibrium with the result that the lowlands become heavier and the highlands lighter, and this difference in pressure causes the solid rocks to move in such a way as to restore the equilibrium. The lowlands sink as rock materials are forced out from under them, while the highlands are forced still higher.

The sinking of the ocean basins must also produce stresses in the surface that result in wrinkles or folds.

The present gradual elevation of the region north of the Great Lakes is thus explained by this principle of isostasy or balancing of weights. When the Great Lakes region was covered with heavy glaciers, it must have sunk because of the increased weight due to the glaciers. Then when the ice melted and the water drained off, an opposite movement was produced to restore the equilibrium. Such movements of the earth's crust take place very slowly, of course, so that thousands of years pass by before equilibrium is restored.

The formation of the Appalachian Mountains is explained by the erosion of a former highland east of the present mountain range, which

filled in a shallow basin extending as far west as Iowa with debris to a depth of 5000 to 20,000 feet. As this basin sank and the neighboring highland rose, lateral pressures were created in the sinking area because the tougher areas surrounding this sedimentary rock would not yield. Something had to happen to relieve the strain, and it is only natural that the weaker sedimentary rocks of the sinking basin would be the ones to buckle up. These folds were then elevated by other isostatic readjustments.

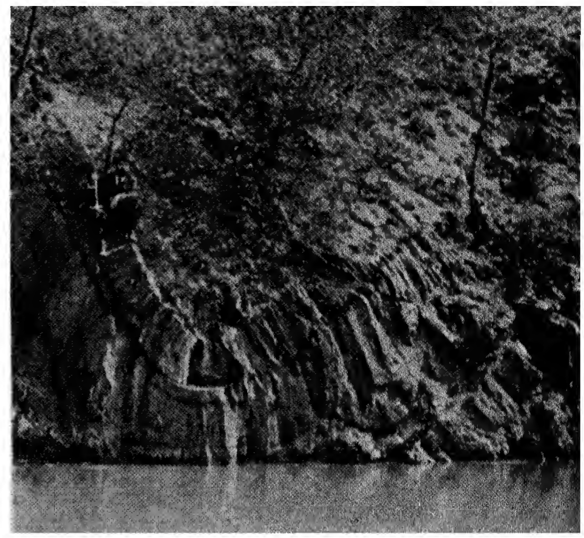


Fig. 45. A fold in a rock stratum. (Courtesy of the U. S. Geol. Survey.)

We have explained the isostatic movement of the earth's surface in words that would indicate that we are sure of our explanation. Actually this theory is the only even partially satisfactory one that has been advanced, and the geologist feels it represents merely the first approach to a complete theory.

Volcanic Activities Bring About Other Important Changes in the Earth's Surface.

Volcanic eruptions occur on the land and in the oceans. Sometimes new islands are thus formed. For example, the island called "Old Bogoslof" in the Bering Sea was raised to an elevation of nearly half a mile by volcanic activity during the period 1796–1823. In 1883 a second island, "New Bogoslof," appeared, while a third island was raised in 1906.

Only about 430 volcanoes have been active within the time of recorded history. Many of the very numerous prehistoric volcanic activities were not the explosive types with their typical spouting of rocks and ash, belching of gases, flames, and smoke from cones, as found in modern volcanoes; but they more closely resembled the great lava flows of Iceland. In 1783, a series of earthquakes in Iceland preceded two great rivers of molten rock that poured out of fissures, 24 miles one way and 40 miles in the opposite direction, covering 200 square miles of land.

Parts of Ireland, the Hebrides, and large sections of Greenland were formed in this way, while 200,000 square miles of the northwestern states of the United States were covered with lava flowing from cracks. This flow is very evident to anyone who visits the Columbia River plateau. This lava may be seen especially well where the Columbia

River and the Snake River have cut through it. Some of these flows were nearly a mile deep and leveled off the landscape. The Deccan plateau in India was once covered by lava flowing from fissures out over nearly 250,000 square miles, to a thickness of 10,000 feet in places. Similar plateaus have been found in South America and South Africa.

The Hawaiian Islands were formed by layer upon layer of lava flows, extending seven miles above the ocean floors, two miles of which are above the sea.

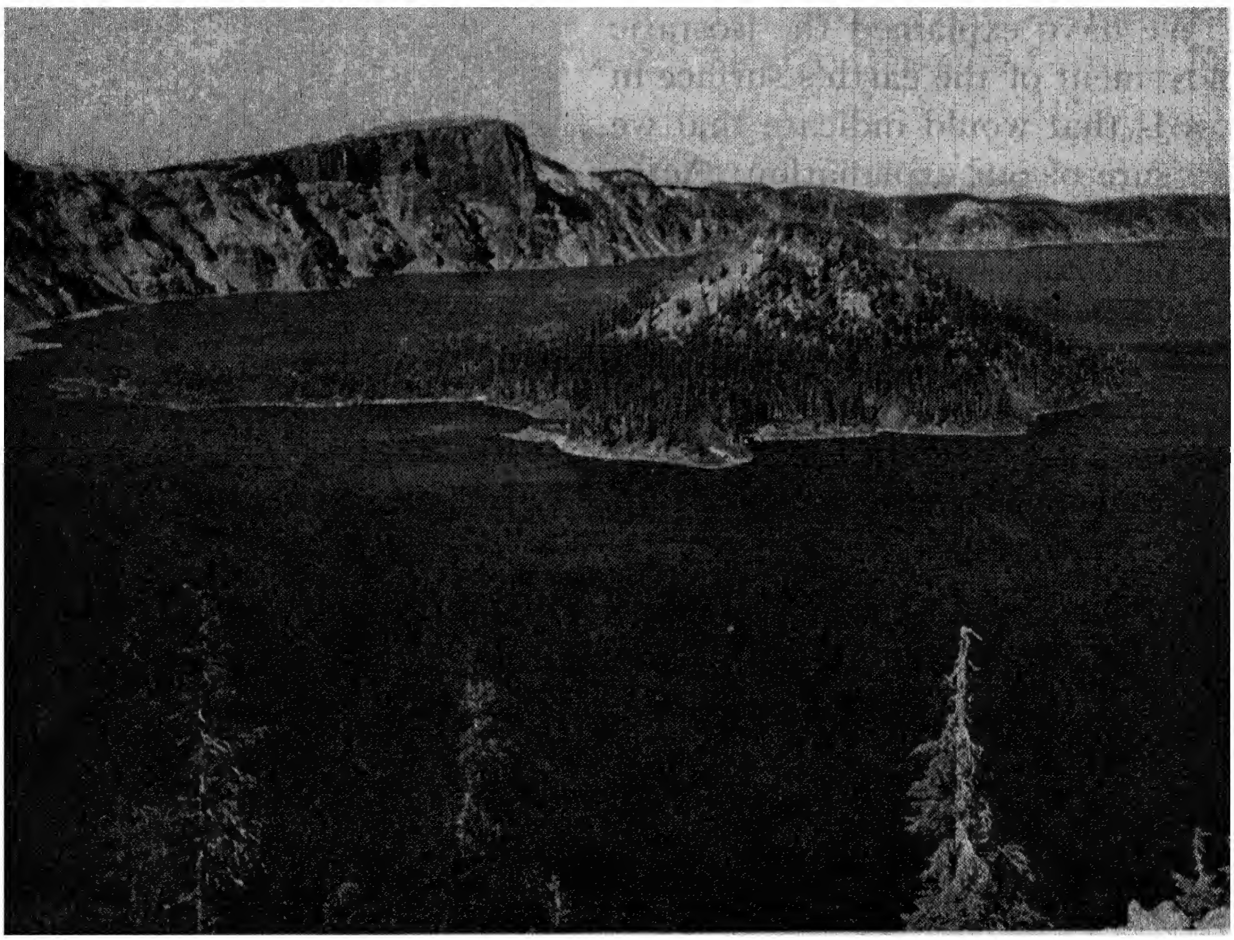


FIG. 46. Wizard Island from the rim near Crater Lake Lodge, Crater Lake, California. Wizard Island is a volcanic cone within the very large crater now occupied by Crater Lake. (Courtesy of the U. S. Dept. of the Interior. Photograph by George A. Grant, 1931.)

The lavas flowing from these fissures, such as occurred in Iceland and the Hawaiian Islands, are dark in color, because they are rich in iron but poor in silica. They flow freely for a long distance and do not cool rapidly, and gases readily escape through the lava.

The lava that flows from the conelike volcanoes is much hotter but cools very quickly to form masses through which gases cannot pass; explosions generally occur, and steep cones are produced. The light-colored lavas are rich in silica but poor in iron. Tremendous pressure may be built up in such volcanoes over long periods of time before they

explode. A volcano in the Tyrrhenian Sea erupted in 1786, pouring forth enormous quantities of cinders and ashes for fifteen days. Then it returned to its former deathlike calm, only to explode again a century later.

Mount Vesuvius is another volcano that explodes without warning. Everyone has heard of the eruption of 79 A.D., which buried the Roman towns of Herculaneum and Pompeii. Its most recent eruption in 1906 was very spectacular. With a tremendous roar a great gas blast shot

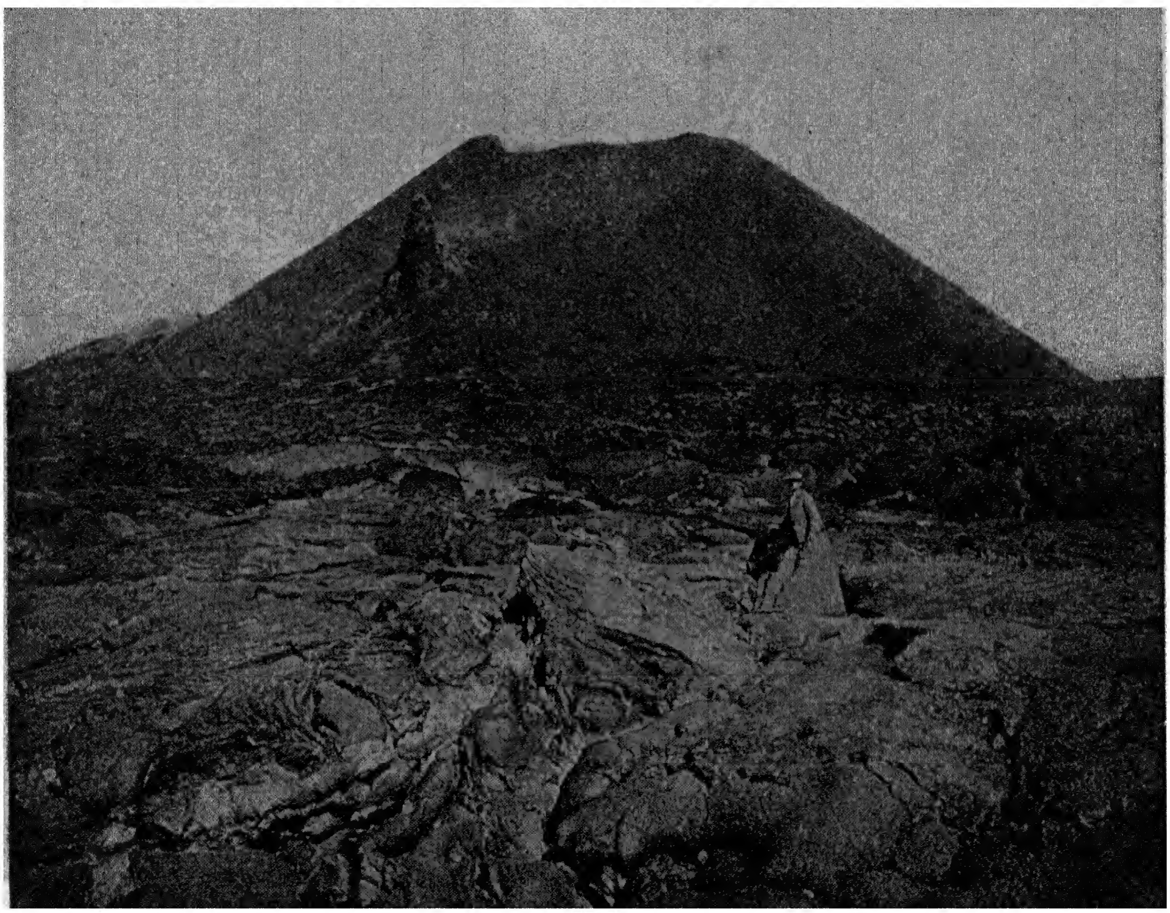


FIG. 47. Cinder cone of Mount Vesuvius. (G. W. Stose, U. S. Geol. Survey.)

eight miles into the air before it began to spread out to form a huge cloud. Mount Vesuvius has been active ever since 1913 and is due to erupt again within a few decades.

Krakatoa, which had lain dormant in the Dutch East Indies for many years, suddenly in 1883 blew more than four cubic miles of its cone into the air. The eruption was heard more than 2000 miles away. Tens of thousands of people were killed, and the dust that shot into the air went around the earth.

The eruption of Katmai in Alaska, in 1912, blew five cubic miles of volcanic ash into the air and produced clouds so dense that the country for a hundred miles around was in darkness for two days. Six inches of ash covered the land as far as 160 miles away.

Tamboro, off the Island of Java, is estimated to have blown out between 28 and 50 cubic miles of material.

Seasons of unusual cold have been experienced after tremendous volcanic explosions which throw volcanic ash to great heights. This dust is not carried down by the rains because it is carried far above them and around the world by the upper air currents. The dust reflects and absorbs much of the sun's heat. The eruption of Tamboro

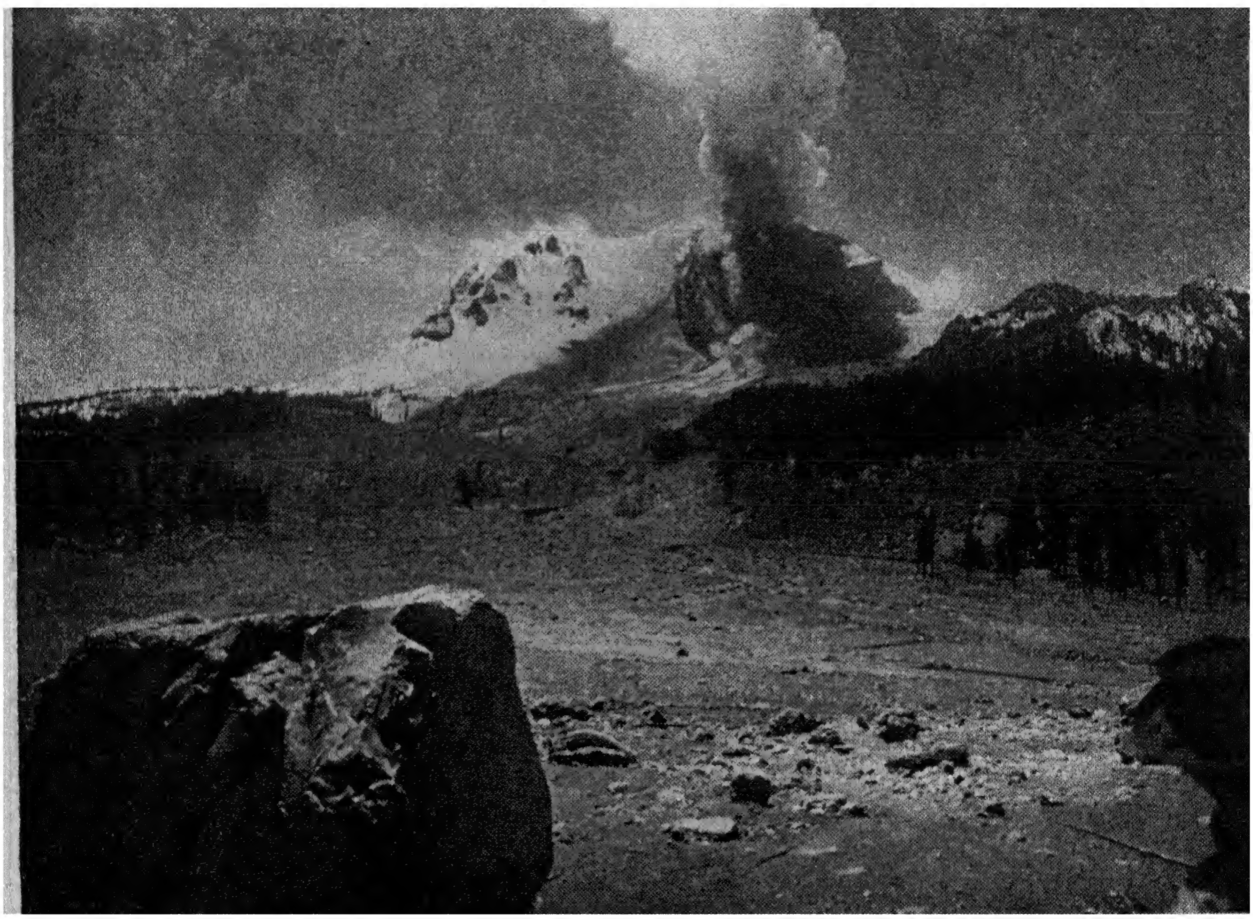


FIG. 48. The Eruption of Mount Lassen in 1915. (Courtesy of the U. S. Dept. of the Interior.)

in the East Indies was followed by "The Year without a Summer" in 1816. In New England snowstorms occurred in June, July, and August of that summer.

Similar cool seasons followed the explosion of Krakatoa in the East Indies in 1883 and of Katmai in Alaska in 1912.

Some of the most noted mountains in North America are volcanic in origin. Among these are Mount Hood, Mount Shasta, and Mount Rainier. Mount Lassen is the only active volcano in the United States. In 1936 it showed signs of renewed activity, after twenty-two years of comparative quiet. The fumaroles, geysers, and hot springs of Yellowstone National Park are characteristic of the final stage of volcanic activity.

These volcanic activities observed on the surface are merely slight indications of the inner turmoil which causes them. All movements of lava and the phenomena connected with these movements are grouped under the name "vulcanism." Many lava flows which did not reach the surface filled in fissures between rocks, forming dikes of hard rock that protrude above the softer rocks around them when they are exposed to weathering conditions. The Palisades of the Hudson were formed by intrusions of lava between beds of rock, forming thick *sills*. In several areas, these intrusions cause the upper layers of rock to bulge upward into dome-shaped hills or mountains, called laccoliths. The Black Hills are typical laccoliths. Lava-filled tubes of volcanoes are called necks. When lava cools so quickly that it does not have time to crystallize, volcanic glass, or obsidian, is the result. Under the high pressures in the earth's interior the materials, although solid, have the capacity to flow slowly and thus bring about equalization of pressure differences on the surface, flowing from the regions of high pressure under regions of lower pressure and thus elevating them.

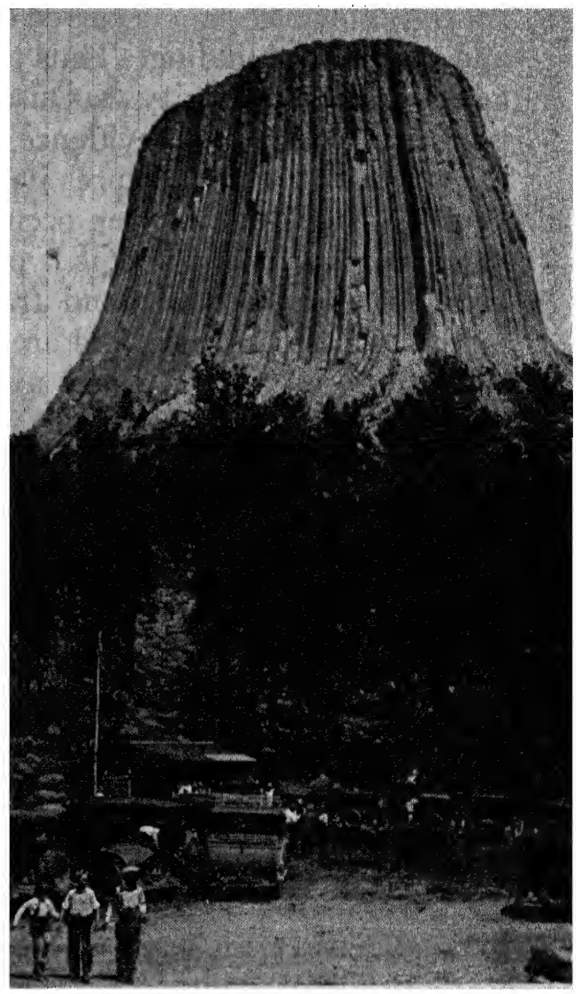


Fig. 49. Columnar jointing, Devil's Tower, Wyoming. (Black Hills Studios.)

It is quite possible that this semifluidity of the interior solid matter of the earth would account for the accumulation of the denser materials at the center and thus make the theory of an original molten earth unnecessary.

Under these conditions of high pressure there must also be molecular rearrangements which would tend to decrease the pressure. Certain changes in the nature of rocks can thus be explained.

Probably molten rock is produced in localized sections of the earth which are under great strain.

Great cracks in the earth's surface afford the outlet for the hot materials below, and volcanoes occur in chains along these cracks. Inasmuch as earth movements also occur along these cracks, volcanic portions of the globe are likewise subject to earthquakes.

STUDY QUESTIONS

1. What processes offset the results of degradation?
2. What is isostasy?
3. What is an earthquake?
4. Recent data suggest the possibility that some earthquakes occur at depths of five hundred miles, but this depth does not seem likely to be a region of fractures. Two views arise: (1) the earthquakes are caused by fractures, and fractures occur at greater depths than is commonly thought; or else (2) (Suggest another possible alternative.)
5. All the known ice ages occurred either during or soon after continental uplifts and mountain-building. Thus the earth may be said to manufacture its own ages. Volcanic activity was also very great during these mountain-building periods. Is there any evidence in this section that would support this idea that the earth manufactures its own ice ages?
6. Why do earthquakes often occur along certain seacoasts?
7. What is a fault, and how is it produced?
8. Why have the eroding and transporting action of the various degrading factors not brought all land areas below sea level?
9. What processes bring about a shift in weight and pressure on the earth's surface?
10. Explain the present gradual elevation in the Great Lakes region.
11. Explain how earthquake centers may be located.
12. Explain the principle of the seismograph.
13. Differentiate between the behavior and nature of the two types of volcanoes.
14. What is the cause of volcanoes?
15. Of what kinds of tremors do earthquakes consist?
16. Is there any reason why earthquake regions should also be volcanic regions?
17. What are the causes of earthquakes?
18. Are there any evidences of present volcanic activity in the United States?
19. What are dikes, sills, and laccoliths?
20. Mention some well-known topographic features that are volcanic in origin.
21. What is diastrophism?
22. Why do earthquakes occur more often in California than in the Mississippi Basin?
23. Give several examples of very destructive explosive volcanoes.

UNIT III

SECTION 6

THE HISTORY OF THE EARTH IS DIVIDED INTO ERAS, PERIODS, AND EPOCHS

The hills are shadows, and they flow
From form to form, and nothing stands;
They melt like mists, the solid lands;
Like clouds they shape themselves and go.
— Source unknown.

Introduction

If we should return to our favorite resort near some mountain stream or lake or seashore in the year 3000, very little change would be noted. We might find that the stream had cut a little deeper channel, that the shores of the lake or ocean had moved a few hundred feet or so, but the general contour of the mountains and the configurations of the coast would be familiar.

But if we should return several million years later, nothing would seem to be the same. Where we had known mountains, plains might exist. New mountain ranges might be observed, and the oceans might now be covering large sections which were formerly high dry land. Our dams and skyscrapers might long since have been ground to powder under a glacier a couple of miles thick.

Suppose that we were to excavate a portion of a city dump that had been gradually built up over a period of two hundred years. In the lower layers we might find old knives, spinning-wheel parts, horseshoes, and handmade square nails. In other layers, sewing-machine parts, cylindrical phonograph records, tin cans, machine-made wire nails, aluminum utensils, and radio tubes would appear for the first time. A study of the contents of these different strata in the city dump would enable us to piece together a fairly accurate story of the developments which took place during the two-hundred-year period. In this same way archeologists are studying civilizations which existed thousands of years ago by excavating the ruins of ancient cities, many of which were found to rest in turn on six or more layers of previous ruins. The geologist obtains a story of the history of the earth by a similar

study of rock strata. It is the purpose of this Section to give a brief résumé of what the geologist has learned about the history of the earth.

Knowledge of the Earth's History Is Quite Recent.

It is only natural that knowledge of the forces and the changes which these forces have combined to produce on the earth had to wait until scientific exploration developed. At the time of Columbus' discovery of America large sections of the earth remained unknown. Nearly three hundred years elapsed before man began to penetrate the wilderness of the Americas.

Baron von Humboldt (1769–1859) spent five years exploring South America and the Mexican Gulf. The results of his numerous explorations were published in four volumes during the period 1845–1858. Other famous explorations were conducted during the nineteenth century, among them the voyage of the *Beagle* (1831) to Patagonia, Chile, Peru, and other points. Charles Darwin was the naturalist on this voyage. Joseph Hooker (1817–1911) and Sir James Ross led another expedition in 1839 to explore the Antarctic. In 1872, the *Challenger* set out on a scientific cruise in the Atlantic and Pacific oceans that lasted for several years.

James Hutton (1726–1797) was the first man to observe and demonstrate that the past history of the earth might be understood through the study of processes that are taking place today.

Tipped Strata Make It Possible to Read the History of Geological Events Long Past Which Have Been Written in Stone.

The thickness of sedimentary rocks which were formed by deposition in river beds, lakes, and oceans may reach several miles — oil has been obtained from oil-bearing strata at depths of 15,000 feet. The study of the cores obtained by oil-well drillers has aided the geologist immensely because it is not feasible to dig shafts 15,000 feet deep or more. Fortunately for the geologist, there are many places on the earth's surface where the strata have been tipped on edge, so that they can be examined on the surface of the earth. Again, nature has dug tremendous holes, such as the Grand Canyon of the Colorado River, which expose many thousands of feet of stratified rock.

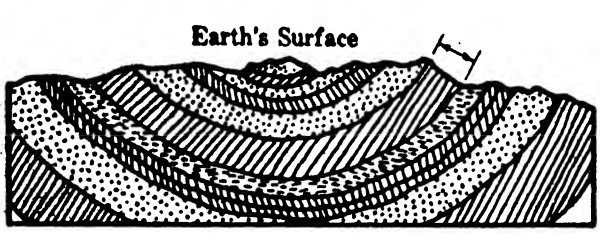


FIG. 50. Tipped strata of rock may be worn away by erosion and left exposed.

Unconformities Are Nature's Method of Recording Lost Intervals of Time.

Occasionally railroad and highway cuts expose stratified deposits in which horizontal strata lie on strata which have been tipped and worn off by erosion, thus leaving a line of demarcation where the strata are not parallel or do not conform to the strata below. Such an angular *uncomformity* may separate two periods or even eras which are typified by great uplifts in the earth's surface.

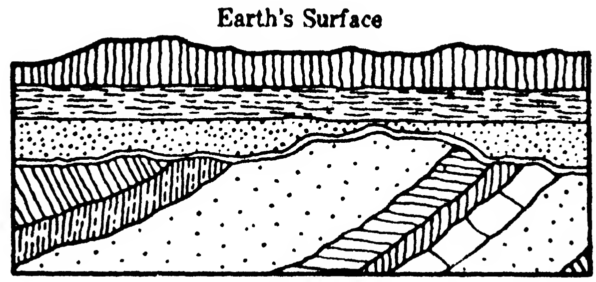


FIG. 51. An unconformity.

Fossils Are Geological Records of Prehistoric Life.

Traces of plants and animals in the rôcks reveal the succession of plant and animal life of the past and its orderly progressive changes to present forms. These indelible traces are called fossils, regardless of their nature.

Relatively few of the countless living organisms have been in a position to form fossils. Living organisms must be buried at death in such media as clay, sand, silt, dust, volcanic ash, or asphalt in order to form

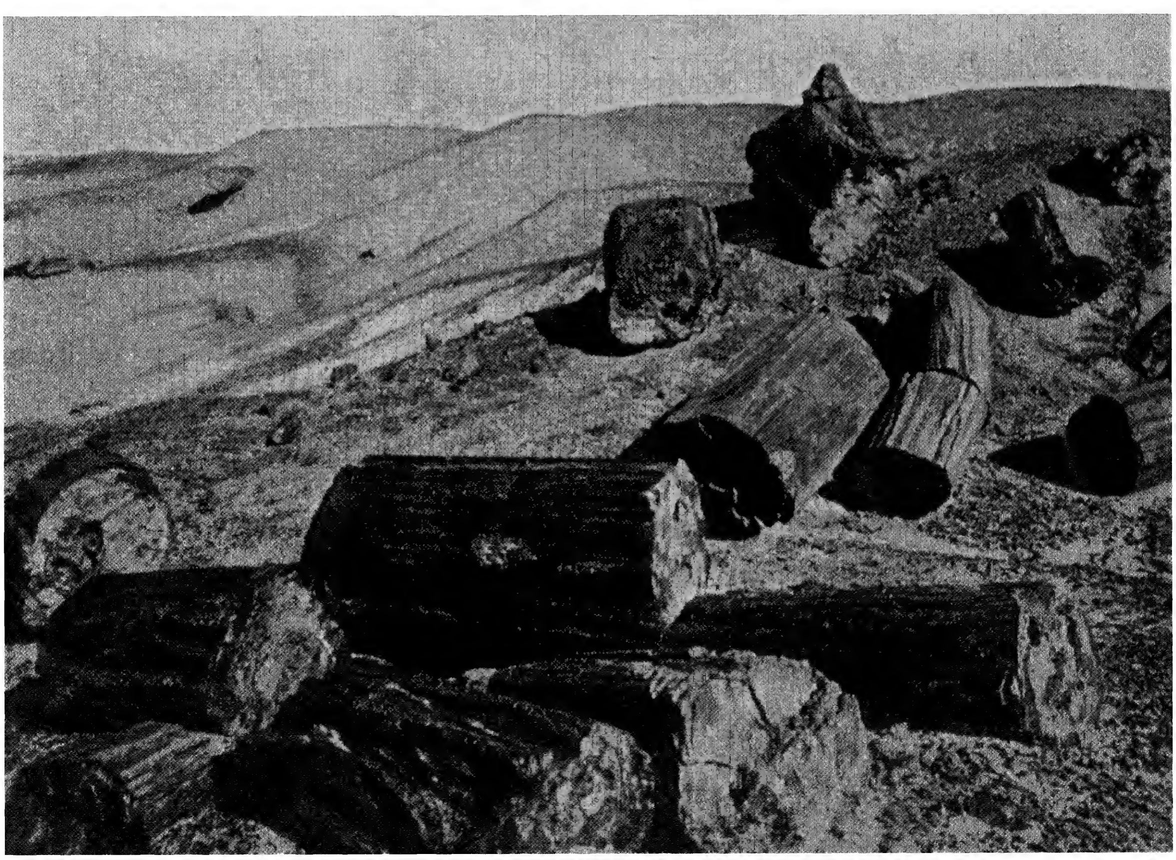


FIG. 52. Scattered fragments of petrified *Aruacarioxylon Arizonicum* in Petrified Forest, Arizona. (Courtesy oi the U. S. Forest Service.)

fossils. Otherwise fungi, bacteria, or animals soon destroy them. Only a few fossils have been formed from soft-bodied organisms.

Carcasses of woolly mammoths have been found frozen in Siberia, so well preserved that their flesh was still edible after thousands of years. Fossil remains consist of the shells, skeletons, and other hard parts of living organisms which contain enough mineral matter to enable them to resist decomposition long enough for them to be covered by deposits which have preserved them in stratified rock until the present time.

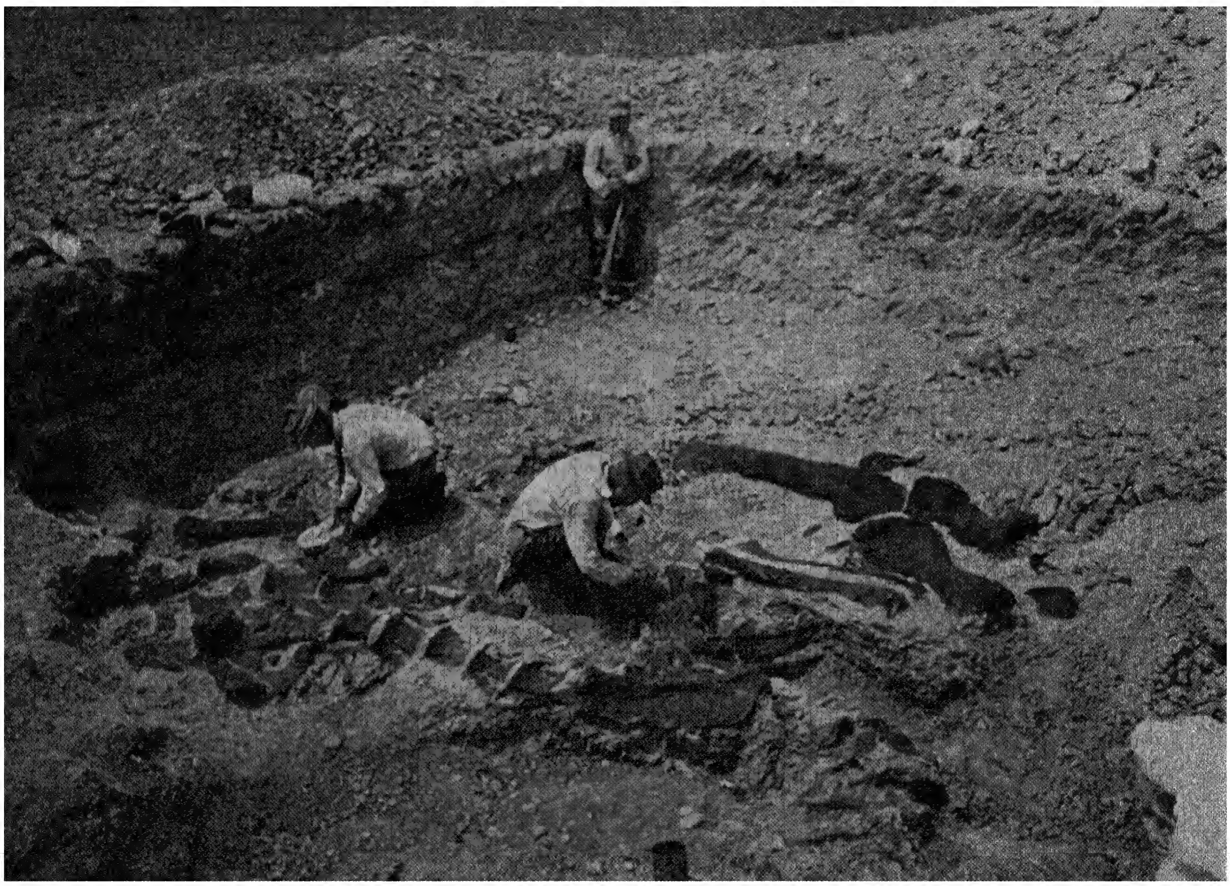


FIG. 53. Uncovering Brontosaurus bones, Bone Cabin Quarry, Wyoming. (Courtesy of the American Museum of Natural History.)

Often *pseudomorphs* are found in the older rocks. A *pseudomorph* is a fossil which has been preserved by the substitution of the original material by mineral matter in such a way as to preserve the original shape and features of the specimen. Petrified trees are pseudomorphs.

Frequently fossil *molds* or *casts* are found. A *mold* is a cavity left in a rock by the complete decay or solution of a dead organism, leaving its form in the sediment. If a mold is later filled with mineral matter which retains the shape of the mold, the fossil is called a *cast.*

Tracks, *trails*, and *furrows* have also been preserved in the rocks.

Peat bogs and asphalt pits have proven to be especially good sources of fossils of animals which have been trapped in them. Coal deposits

often show patterns of leaves, while volcanic ash and lava yield fossil remains that have been caught and petrified in these deposits. In the Mojave Desert there is a thick stratum of volcanic ash that probably settled in a lake and covered over branches and trunks of trees, which were then petrified as they lay in this sediment at the bottom of the lake.

The fact that the types of fossils in different rock layers vary from simple one-celled organisms in the lowest rock layers to the complex mammals in the top layers indicates that life has not always existed

FIG. 54. Dinosaur tracks in sandstone in the Peace River Canyon, British Columbia. (Courtesy of the Department of Mines and Resources, Canada.)

on the earth in its present forms but has passed through an evolutionary process. Repeated observations have shown that rocks of a given period contain fossils peculiar to that period. Geologists who specialize in the study of fossils are called *paleontologists;* they are able to date a given stratum by an examination of the microscopic and other fossils which it contains. This identification of strata is very important in petroleum geology, because it enables the geologist to examine oil-well cores and tell what stratum is being drilled and when a stratum which usually contains oil may be expected to be reached.

The History of the Earth Is Divided into Eras, Periods, and Epochs on the Basis of Major Topographical Changes.

Each era consisting of millions of years represents a time of widespread mountain-building; each period represents local disturbances and uplifts of relatively short duration; an epoch is a subdivision of a period. Each period begins with increasing submergence of lands and closes with the retreat of the sea.

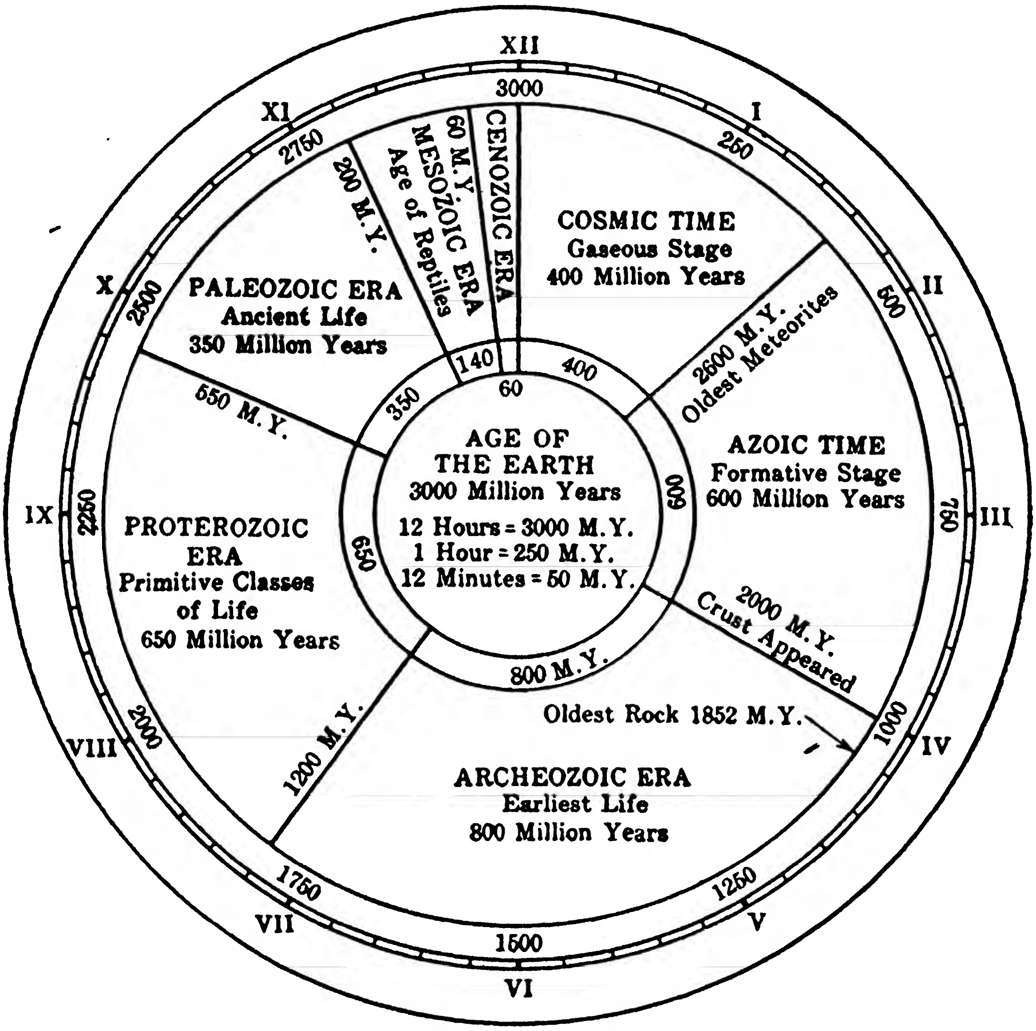


FIG. 55. Summary of the earth's history in a clock's face. (Courtesy of Chester A. Reeds, the University Society, and the American Museum of Natural History.)

The study of the history of the earth has required a tremendous amount of careful piecing-together of fragments of evidence. The broad outline is fairly well established in much more detail than is possible to present in this book. The authorities differ as to the length of some periods by a million years or more; but a million years is but a moment in geological time, and all figures are rough estimates at best. The following synopsis of the earth's history represents more or less a cross section of modern geologists' interpretations of the data they have gathered.

Synopsis of the Earth's History

Starting with the oldest eras

Era	Estimated Time	Period	Important Changes in the Earth's Surface	Important Organic Events
Archeozoic Era	Probably longer in duration than all succeeding eras. About 800,000,000 years	Three periods are recognized 1. Keewatin 2. Laurentian 3. Unconformity	Evidences of erosion, sedimentation, and volcanism. Graphite and limestone deposits formed	No evidence of life, primitive one-celled organisms may have existed
Proterozoic	500,000,000 to 650,000,000 years	Lower Proterozoic	First glaciation noted	Bacteria-seaweed
		Middle Proterozoic	World's greatest iron deposits formed	
		Upper Proterozoic	Large amount of volcanism in Central and Eastern North America. Deposits of gold, silver, copper, and nickel	Evidence of great development of the invertebrates
		Unconformity	Extensive glaciation	
Paleozoic	90,000,000 60,000,000	Cambrian Ordovician	North America largely submerged	First vertebrates obstracoderms, many invertebrates, trilobites, brachiopods, etc.
	About 25,000,000	Silurian	Waters recede. Scottish Highlands formed	First air breathers, scorpions, land plants appear
	40,000,000	Devonian	Continents generally submerged	First forests and amphibians
	30,000,000	Carboniferous Age: Mississippian	Coal beds form in Europe	Sharks noted
	45,000,000	Carboniferous Age: Pennsylvanian	Largest coal deposits laid down	First reptiles — great forests
	40,000,000	Carboniferous Age: Permian	Appalachian Mountains form, general continental uplifts	Unfavorable conditions reduce all types of life

SYNOPSIS OF THE EARTH'S HISTORY — *Continued*

	Estimated Time	Period		Important Changes in the Earth's Surface	Important Organic Events
Mesozoic	25,000,000	Triassic		General aridity	Age of reptiles — First primitive mammals, Cycads prominent
Mesozoic	25,000,000	Jurassic		Sierra Nevadas formed	First birds — gigantic reptiles — flying and marine
Mesozoic	20,000,000	Early Cretaceous		Interior seas in North America	First flowering plants — modern insects Toothed birds and flying reptiles
Mesozoic	40,000,000	Late Cretaceous		Rockies and Andes formed. Chalk and coal deposits	Mesozoic types of reptiles and birds become extinct
Cenozoic	20,000,000	Tertiary Period	*Epoch* Eocene	Extensive non-marine deposits	First modern marine invertebrates. Mammals begin to dominate
Cenozoic	10,000,000	Tertiary Period	Oligocene	Much erosion — warm climate	Carnivores and ungulates — ancestral elephants
Cenozoic	15,000,000	Tertiary Period	Miocene	Birth of Alps, Himalayas — volcanism in Western North America	First Old World Apes. Horses and elephants develop
Cenozoic	10,000,000	Tertiary Period	Pliocene	World-wide uplift continued	Horses and elephants approach modern appearance
Cenozoic	1,000,000	Quarternary Period	Pleistocene	Period of periodic glacial advances	First Men — Heidelberg Neanderthal Cro-Magnon
Cenozoic	25,000	Quarternary Period	Holocene	No great changes Erosion — local volcanism and diastrophism	Stone Age — 18,000 B.C. Bronze Age — 3500 B.C. Iron Age — 1350 B.C.

The History of North America Shows That Our Great Natural Resources Were Not Achieved without Many "Ups and Downs."

Away back in the Archeozoic era, when one-celled animals first put in their appearance and when sedimentation and mountain-building were going on as they do today, there was probably land at some points where North America is today. During the Archeozoic era, some of the richest deposits of nickel, silver, gold, copper, and iron that we are now mining in the United States and Canada were formed. The locations of the present Appalachian and Rocky Mountains were huge elongated depressions occupied by areas of the ocean, and for the next few periods, extending into the Paleozoic era, North America was flooded by the oceans a number of times. During the Ordovician period at least three fifths of North America was flooded with shallow water. Great beds of limestone, shale, and sandstone were formed during the Devonian and Silurian periods. During the late Silurian times the hot dry climate evaporated large bodies of water and formed layers of salt and gypsum several hundred feet thick. These layers are now found at depths of 2000 feet or more in New York. The iron-ore deposits of Alabama were of Silurian origin.

During the Pennsylvanian period the great Pennsylvania coal fields were formed, and the strata of organic materials from which petroleum was formed were buried under many layers of sedimentary rocks. During the Permian period the seas retreated from the central portion of North America, and great deposits of salt and gypsum were formed in the region extending from Kansas to New Mexico. By the close of the Paleozoic era the Appalachian trough had filled up with sediment in excess of 40,000 feet in depth and the Paleozoic era was brought to a close by widespread uplifts of the continent. The Appalachian Mountains were formed at this time.

During the fourth, or Mesozoic, era North America was inhabited by huge reptiles such as the fierce Tyrannosaurus, 50 feet in length, and the 75-foot Brontosaurus. Luxuriant vegetation must have been required to meet the daily needs of the 50-ton herbivorous Brachiosaurus. The great Rocky Mountain Trough remained as an inland sea for millions of years; but it gradually filled up, petroleum deposits and coal beds were formed, and, by the end of this era, the Rocky Mountains were lifted up.

About sixty million years ago, at the beginning of the Cenozoic era, the principal continental features of North America were about as we see them today; but few of the present topographical features, such as the plains, hills, valleys, and canyons that are familiar to us, existed at that time. During the Tertiary period the Florida peninsula and

the western and southwestern portions of the continent were submerged.

Mount Rainier in Washington and Mount Shasta in California were active volcanoes, and many lava flows occurred, some 5000 feet in depth.

Toward the close of the Tertiary period the Cascade and Coast Ranges in western North America were uplifted, the whole Rocky Mountain area was elevated, and the Colorado River began cutting the Grand Canyon.

Even an Epoch Is a Long, Long Time.

The Pleistocene epoch of the Quarternary period of the Cenozoic era includes a very brief time, only one million years, in the history of the world; and yet it was during this period that horses and elephants approached their modern form and the Cro-Magnon man developed. During this epoch there were five great ice ages, in which large sheets of ice, possibly thousands of feet thick, moved down into the part of North America now occupied by the United States as far as Illinois and Ohio and receded again. Great ice floes seem to be peculiar to this period and rank high in importance as terrestrial events. Each of these ice ages lasted for tens of thousands of years, and between each there were warm periods which were at least fifty thousand years long.

About twenty thousand years ago the last great glacier retreated, leaving behind it the Great Lakes and thousands of smaller lakes in northern United States and in Canada. Niagara Falls is estimated to have taken 20,000 years to cut its way to its present position from the place where it started as the last glacier receded — hence the conclusion that the last glacier was receding 20,000 years ago. This glacier still covers a large portion of Greenland and regions around the North Pole to an extent of 6,000,000 square miles. If it melts, it is estimated that the level of the sea will be raised about 150 feet.

We are still living in a comparatively cool period of the earth's history. A few millions of years ago the earth was warm to the poles, as proven by the rich coal deposits in Alaska.

STUDY QUESTIONS

1. What is meant by an unconformity, and of what value is it to the geologists?
2. How is the geologist able to study successive layers of stratified rock?
3. How would you account for the formation of salt beds?
4. When were the coal beds formed? What climatic conditions probably existed when the coal beds were laid down?
5. Which of the mountain ranges in the United States is (*a*) the oldest, (*b*) the youngest?

6. How would you account for the rather sudden demise of the dinosaurs?
7. If each minute should represent 1,000,000 years, how long has the earth been in existence? How long has man been in existence?
8. In the place where your home town is located, what was the probable condition of the earth's surface during (*a*) Ordovician, (*b*) Devonian, (*c*) Permian, (*d*) Jurassic time?
9. What evidence can you give to prove that the earth's surface has undergone many changes?
10. Upon what basis are divisions in geological time made?
11. At what periods was a large portion of North America under water?
12. Of what value is the study of fossils to the scientist?
13. How does the paleontologist identify rock strata?

UNIT III

SECTION 7

GEOLOGICAL PROCESSES PRODUCE MANY DIFFERENT KINDS OF ROCKS

Introduction.

For half a million years or so, early Eolithic man was content with the improvisation of natural stones for use as hammers or knives. We no longer live in the Stone Age,[1] but it is probable that more stone is being used by modern man than ever before in man's history, because of the refined tools which we have available for handling rock.

The solid portion of the earth is made up of three classes of rocks: *igneous*, *sedimentary*, and *metamorphic*.

Igneous rocks were produced by high temperatures; sedimentary rocks are those which were produced by deposition (by water or wind); and metamorphic rocks are produced by changes in the above two types of rocks.

Igneous Rock Was Molten at One Time.

Igneous rock was produced by high temperatures. If the earth was molten at one time, all of this molten rock was the original rock. Most of the igneous rock of today, however, undoubtedly represents later forms of rock which were liquefied below the surface and returned to the surface again by lava flows, volcanic activities, or isostatic readjustments.

This molten rock, called "magma," generally contains superheated steam and other gases, whose rapid expansion in a volcanic eruption causes the magma to spray out into the air, where it cools quickly to form volcanic dust. When the slower bodies of magma work their way up through fissures in the rocks, they solidify to form layers of lava on or beneath the surface.

Pumice is formed by the cooling of the froth produced in the magma by the rapid expansion of dissolved gases as the result of the lowering of pressure on reaching the surface. If certain lavas cool quickly, volcanic glass or "obsidian" is formed, as has been previously mentioned. Slower cooling produces fine-grained, igneous rocks. The grain

[1] Except perhaps mentally and in some places politically.

is larger if the magma cools still more slowly. A distinguishing characteristic of igneous rocks is their massive and uniform structure.

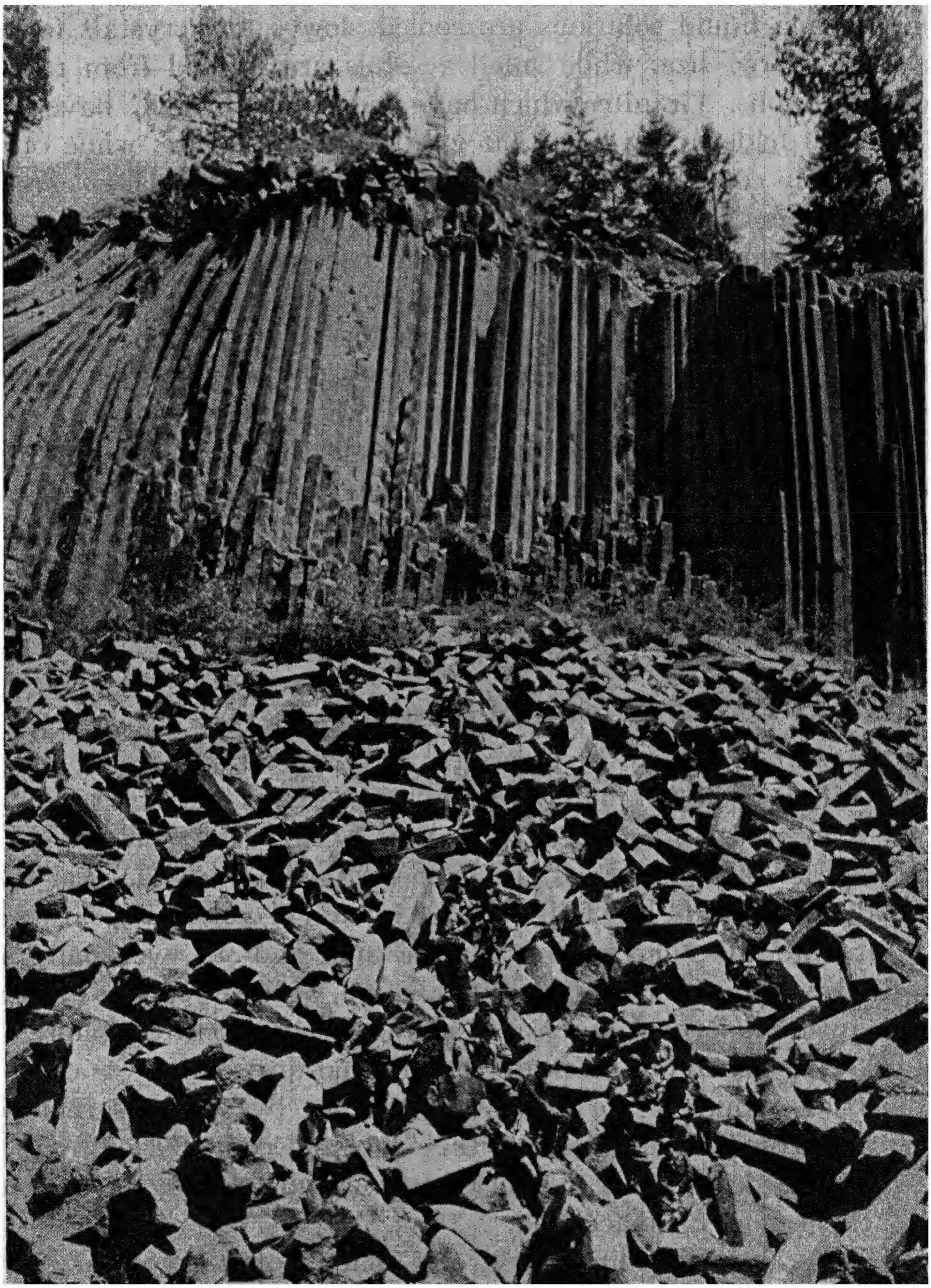


FIG. 56. An example of igneous rock. Close-up of Devil's Post Pile National Monument on San Joaquin River, Sierra National Forest, California. (Courtesy of the U. S. Forest Service.)

There are two forms of igneous rocks which are quite well known, namely, granite and basalt. Granite is a mixture of the minerals (*a*

mineral is a pure material or nearly pure material that occurs in nature), quartz (*i.e.*, silicon dioxide), feldspars, and white micas (*i.e.*, complex silicates of sodium, potassium, aluminum, calcium, magnesium, and iron). When liquid solutions are cooled slowly, the crystals formed grow to a large size, while small crystals are formed from rapidly cooled solutions. Granites which have been formed slowly have large quartz and feldspar crystals that give a coarse texture, while other, more rapidly cooled granites have small quartz and feldspar crystals and consequently a fine texture.

Basalt contains crystals which are microscopic in size and therefore presents a homogeneous appearance; it contains less quartz and more calcium, magnesium, and iron compounds than the granitic rocks. The chief constituents of the basalts are hornblendes and black mica. The lower melting-point of basalt results in liquid magma, which flows more rapidly and cools more quickly. This is the magma of which the cone type of volcanic mountains is generally made. The basalts are denser than the granites and are found chiefly under the oceans. Mountains like the Rocky Mountains, which have been pushed up from below, are largely granitic in nature. Granite is widely used as a building-stone.

Sedimentary Rock Is a Product of Erosion.

Sedimentary rock can be identified by characteristic strata formed by deposition of eroded material from water. The layers are produced by the uneven rate of sedimentation; thus a full, rushing stream of the spring carries more materials and carries larger particles farther than the shallow stream of late fall. Again a stream is constantly eating its way into the hills, moving so that the mud and silt eventually are dropped where the sand was deposited before, while the sand is dropped farther upstream where the gravel was formerly deposited before the rapid-flowing portion of the water had moved upstream.

Layers of sediment are cemented together by minerals removed chemically from the water; and as these layers become buried by layer after layer of rock up to a thickness of thousands of feet, the pressure makes them more compact.

Conglomerates are sedimentary rocks made from the coarser gravel and sand. Sand, which is nearly pure quartz produced from the disintegration of granite, is cemented together to form sandstone. The smaller sedimentary particles (*i.e.*, the silt and clay) form the characteristic laminated shales.

Some of the black-shale deposits contain vast quantities of petroleum, which can be separated, but not at a cost that will compete with

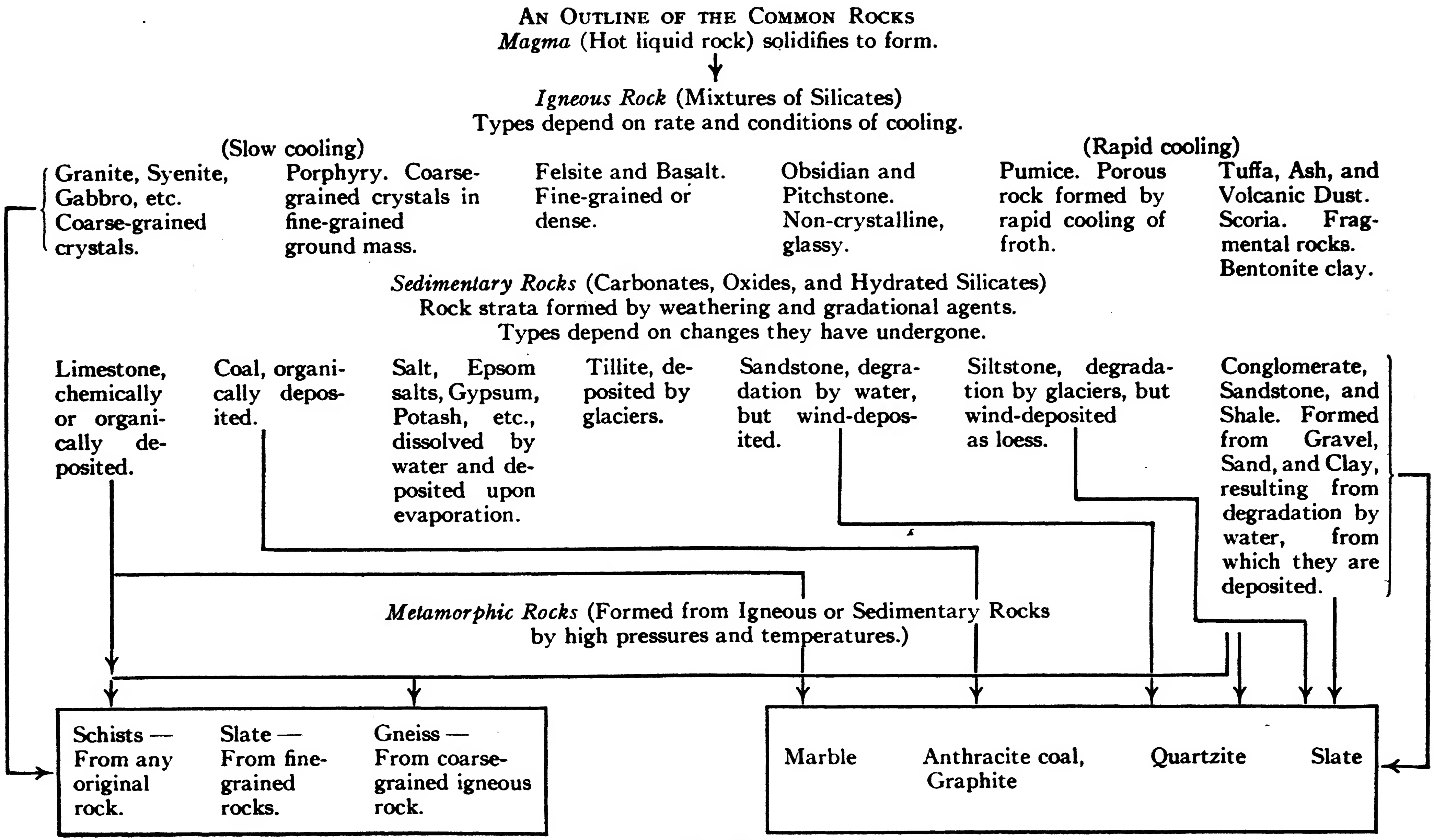

AN OUTLINE OF THE COMMON ROCKS
Magma (Hot liquid rock) solidifies to form.
Igneous Rock (Mixtures of Silicates)
Types depend on rate and conditions of cooling.
(Slow cooling)
(Rapid cooling)
Granite, Syenite, Gabbro, etc. Coarse-grained crystals.
Porphyry. Coarse-grained crystals in fine-grained ground mass.
Felsite and Basalt. Fine-grained or dense.
Obsidian and Pitchstone. Non-crystalline, glassy.
Pumice. Porous rock formed by rapid cooling of froth.
Tuffa, Ash, and Volcanic Dust. Scoria. Fragmental rocks. Bentonite clay.
Sedimentary Rocks (Carbonates, Oxides, and Hydrated Silicates)
Rock strata formed by weathering and gradational agents.
Types depend on changes they have undergone.
Limestone, chemically or organically deposited.
Coal, organically deposited.
Salt, Epsom salts, Gypsum, Potash, etc., dissolved by water and deposited upon evaporation.
Tillite, deposited by glaciers.
Sandstone, degradation by water, but wind-deposited.
Siltstone, degradation by glaciers, but wind-deposited as loess.
Conglomerate, Sandstone, and Shale. Formed from Gravel, Sand, and Clay, resulting from degradation by water, from which they are deposited.
Metamorphic Rocks (Formed from Igneous or Sedimentary Rocks
by high pressures and temperatures.)
Schists — From any original rock.
Slate — From fine-grained rocks.
Gneiss — From coarse-grained igneous rock.
Marble
Anthracite coal, Graphite
Quartzite
Slate

FIG. 57.

present petroleum production. Limestone is another type of sedimentary rock formed from the remains of the shells of mollusks, coral, and other invertebrate animals, by the action of calcareous algae and bacteria, and also by chemical precipitation.

Sedimentary rocks frequently contain fossils, which vary in size from the microscopic fossils to the huge fossils of trees or the dinosaurs.

Some of the green and brown algae specialize in removing calcium carbonate from water to form external coatings for themselves. There are some large pinnacles of calcium carbonate at the lower end of Searles Lake, California, that were formed by such algae when the lake level was much higher than at present. Some of the Paleozoic limestone of the Rocky Mountains was formed by similar algae. One genus of green algae, the stonewort, is reported to deposit 100,000 tons of calcium carbonate yearly from a small lake in Wisconsin.

Other algae, the diatoms, extract silica from the water, and their bodies form siliceous deposits which have formed layers three hundred feet in depth, extending over many square miles. Such deposits, called diatomaceous earth, are mined for use as mild abrasives.

Limestone is used in metallurgy and as a building-stone. Limestone, impregnated with solutions of phosphates washed from thick deposits of bird droppings and other sources, serves as a useful fertilizer.

Sedimentary rocks can be readily recognized as such because they are stratified and may be broken apart along the bedding planes separating the different layers.

Metamorphic Rocks Are Produced by Changes in Sedimentary and Igneous Rocks.

Metamorphic rocks are produced by the action of heat and high pressures on other forms of rocks. Slate is a good example of a metamorphic rock and is produced by the combined effect of heat and pressure on shale. It is easily split into sheets, which are valuable for blackboards and roofing.

Marble is produced by the effect of high pressures and temperatures on limestone. In this process the fossil shells may lose their identity; and part of the calcium carbonate crystallizes, the small crystals giving marble its typical appearance. Marble is widely used as a building-stone because of its durability and beauty. The different colors in marble, like those in rocks of other types, are produced by small amounts of different mineral and organic substances present as accidental impurities.

STUDY QUESTIONS

1. What is an igneous rock?
2. Why are some granites fine-grained and other granites coarse-grained?
3. What are the characteristic features of igneous rocks?
4. What are the characteristic features of sedimentary rocks?
5. How may the age of a given sedimentary rock fragment be determined?
6. Outline the most important type of rocks, and give one or more common examples of each type.
7. Give some examples of igneous rocks formed by volcanic activities.
8. What types of rocks might a kitchen cleanser contain?
9. In how many different ways may limestone be formed?
10. What is a metamorphic rock? Give some examples. Study the chart on p. 181 before attempting to answer the following questions:
    (1) Would rock salt be classified as a rock, and if so, what type of rock is it?
    (2) Name five useful sedimentary rocks.
    (3) Classify the following rocks: (*a*) granite, (*b*) soft coal, (*c*) limestone, (*d*) sandstone, (*e*) marble, (*f*) anthracite coal, (*g*) slate, (*h*) conglomerate, (*i*) pumice, (*j*) obsidian.

UNIT III

SECTION 8

GEOLOGICAL PROCESSES SEGREGATE MANY VALUABLE MINERALS

Introduction.

The might of a modern nation is measured today not in terms of man power alone, but partly also in terms of strategic *minerals*, *i.e.*, pure substances which occur in nature.

The United States contains nearly 40 per cent of the known mineral reserves of the world — it is the only country that possesses fairly adequate reserves of the important industrial minerals. The United States has 25 per cent of the world's iron resources and large amounts of copper, lead, zinc, sulfur, phosphates, potash, petroleum, natural gas, and coal.

In spite of its general richness, however, the country suffers from certain deficiencies among the minor metals. At present it appears that there are inadequate supplies of nickel, tin, manganese, platinum, chromium, mercury, antimony, cobalt, bismuth, tungsten, vanadium, cryolite, asbestos, barite, and graphite.

Many fortunes are made and lost in the attempt to discover new mineral deposits. It is very fortunate for man that various types of materials have been segregated. Even then man has to use the utmost ingenuity to discover and work these deposits.

Man Is Now Living in the Age of Metals.

The first discovery of smelting (*i.e.*, extraction of metals from their ores) was probably made when lumps of iron or copper ores were reduced in a wood fire. Since that time man has been fitfully searching for new ore deposits and working out new methods of separating metals from their ores. Ore deposits consist of minerals which have been segregated; it would be too costly to try to separate the rarer ones from a more or less homogeneous mixture of all of them.

The original deposits of metals and metallic compounds were formed in various ways. The dense minerals were brought to the surface by magma. Some of the heaviest minerals settled out of magma, thus

effecting a separation based upon gravity. Other minerals crystallized as the magma cooled or were expelled in the form of gases and liquid solutions. These solutions then deposited the minerals as a result of temperature or pressure changes or of reaction with other substances. Some minerals occur in veins, as a result of the formation of the deposits from such solutions in fissures. In all cases, the occurrence of the heavy metals near the surface is contrary to gravity; their densities are greater than the densities of the rocks and soil. It is to be expected that mountain ranges which have been formed from materials lifted up from below would be the chief source of the heavier minerals; the majority of mines are located in mountain ranges.

As iron and other metals came into use, copper was largely displaced; but the demand for copper was increased again a few decades ago when the development of electricity created the need for a cheap but good conductor of electricity. Copper is also widely used alone or in alloys because of its resistance to corrosion.

Native copper has been found in numerous deposits throughout the world. One of these deposits of free copper was found in 1841 in Michigan. Some of these huge lumps, which were formed in the gas cavities of immense lava flows, weighed as much as five hundred tons. Later large deposits were found at Butte, Montana. These deposits were produced by solutions. The copper crystallized in cracks in the cooling granite and in the surrounding rocks, from which it was leached and redeposited in a very rich lower layer. Ten billion pounds of copper have been taken from this deposit, and huge reserves remain. Other rich deposits have been found in Utah, Nevada, Alaska, and Arizona. Arizona is now the largest-producing state. The United States produces about two thirds of the world's copper supply.

The Iron Age really began about 1000 B.C., but it came into its maturity about a hundred years ago with the advent of steam engines and the railroad. Soon iron was used in constructing large buildings, steamships, and all kinds of machines. The main deposits of iron are of sedimentary origin. There is one deposit in the Mesabi Range near Lake Superior which alone supplies more than a third of the iron used in the world. Some investigators believe that it was formed by the action of air and circulating water on the uplifted beds of magma, rich in iron silicate, which flowed out into the ocean floor. The more soluble materials were dissolved out of the lava bed, leaving the highly insoluble iron oxide behind. In a similar fashion the deposits of iron, for the control of which nations have fought, may have been formed in the Lorraine region in Europe.

Aluminum has been made available in the form of aluminum oxide

ore (bauxite) by the action of water containing carbon dioxide on feldspar.

Tin was early found to alloy with copper to form bronze. Tin does not occur widely. England has some tin mines in Cornwall, but the most important mines lie in a region extending southward from Burma and Siam to the Islands of the Dutch East Indies. There is also a rich deposit 16,000 feet high in the Bolivian Andes.

Lead and zinc are two other important metals that man uses today. Deposits of many other metals have been found, and man is constantly seeking new uses for them.

Platinum and gold are heavy metals usually found in an uncombined condition in veins where they were deposited or in the bottom of streams where they have settled below the less dense gravel as a result of the erosion of the original lodes. Both gold and silver are deposited in fissures from solutions working upwards from lower deposits.

The original "mother lode" in California, about a mile wide and a hundred miles long, contains gold-bearing veins whose content per ton is worth about $3.00 or $4.00 or more; but the disintegration of large portions of this mother lode, followed by the sorting-out processes of erosion, produced fabulous gold deposits, some of which were worth $200 to $300 per shovelful.

Today man is working the richer mother-lode veins, duplicating the processes of nature. The ore is crushed to a fine powder in stamp mills; and then it is either mixed with water and run over concentrating tables, where the heavier gold and silver minerals separate out by gravity, or it is mixed with chemicals which cause these minerals to float off in a froth. Frequently the powder from the stamp mills is mixed with water and run over a sloping copper plate coated with mercury, which retains the gold as it settles out of the mixture.

Man sometimes even resorts to the chemical-decomposition processes and dissolves the gold with cyanide. The gold is then precipitated from the cyanide solution by adding finely divided zinc.

Colin G. Fink has predicted that the next age will be that of aluminum. It is the most abundant metal in the earth's crust. There are 8 pounds of aluminum for every 5 pounds of iron and every 0.002 pound of copper. The known supplies of copper at the 1929 rate of consumption will last only 40 or 50 years.

The history of man is closely tied up with that of the prospector in his search for new deposits of metals.

Vast Deposits of Useful Salts Have Been Found.

Some of the salt deposits were formed under conditions which caused the different salts in the ocean water to separate out one at a time.

At some places Epsom salts and gypsum (magnesium and calcium sulfates) have been formed. At other locations borax and soda have been deposited. Some of the richest deposits of borax and soda in the world have been located in the ancient lakes of the Mojave Desert, which acted as great catch basins for the water from the surrounding mountains.

Twenty billion tons of valuable potassium salts were formed by the evaporation of a great inland sea to form the present great Stassfurt deposits in Germany. Similar deposits have been found far underground extending for many miles under portions of Oklahoma and Texas.

Another exceedingly valuable product, common salt, is obtained in some sections of the world today by the evaporation of ocean water or desert lakes or the water pumped from wells. Salt has been laid down in huge deposits in many parts of the world by the evaporation of inland seas. It has been estimated that if the salt in the ocean were separated by evaporation, there would be an amount sufficient to cover the surface of the earth to a depth of 112 feet.

Sulfur Is an Important Mineral.

Volcanic activities have produced large deposits of sulfur which were formed by the cooling or the interaction of volcanic gases. The action of carbon compounds with gypsum is thought to be responsible for the huge underground deposits of sulfur in Louisiana and Texas.

Precious Stones Are Valuable Because of Their Beauty.

During all recorded history man has valued jewels and precious stones. He has valued them for their beauty and has often endowed them with imagined powers for good or evil.

Only three minerals possess the requirements, beauty, durability, and rarity, which characterize precious gems; the precious gems are diamond, corundum, and beryl. The ruby and sapphire are varieties of corundum, while the emerald is a variety of beryl.

Beauty is associated with such factors as color, luster, transparency, and sparkle. The beauty of the diamond is due to the last three of the above factors, while the beauty of the emerald is due chiefly to its green color.

All gem stones are sold on the basis of the carat,[1] which is 200 milligrams in weight.

A gem is any mineral, precious or otherwise, which has been polished. When a gem has been cut and mounted in some kind of setting, it is called a jewel.

The majority of precious stones are only special varieties of common substances. Aluminum oxide (corundum) is a common mineral; but when it occurs in blue or red colors, we have sapphires and rubies worth from $500 to $5000 a carat.

Most of the gems owe their colors to impurities. Thus ordinary quartz (silicon dioxide) is not highly valued, but quartz colored with a little iron or manganese oxide gives us our highly valued purple amethysts. Quartz occurs as rock crystals, rose quartz, and milky quartz. A dense, translucent variety of silicon dioxide is known as *chalcedony*, some forms of which are agate, sardonyx, carnelian, jasper, onyx, and opal. Of the more than 1500 known minerals, approximately 50 are used as gems.

The diamond is a crystalline form of pure carbon which was probably produced from carbon trapped in molten rocks.

Most of the precious stones may be synthesized today. With the discovery of this synthesis, superstition surrounding precious stones has decreased, and their values have changed. Now they are valued for what they are rather than for their rarity.

Minerals Are Identified by Their Physical and Chemical Properties.

It is clear that one may have to examine a great many properties before a sure identification can be made. This is why a knowledge of chemistry is always a useful and sometimes a necessary supplement to microscopic examination and physical tests.

Quartz resembles calcite in appearance, but calcite can be scratched with a knife and quartz is too hard to be scratched with a knife. The hardness of a mineral is of considerable aid in its identification. The hardness scale is as follows: 1, talc; 2, gypsum; 3, calcite; 4, fluorite; 5, apatite; 6, orthoclase feldspar; 7, quartz; 8, topaz; 9, corundum; and 10, diamond. The hardness of a mineral is determined by finding which of the above minerals will scratch it and which of these minerals it will scratch.

The specific gravity, *i.e.*, its weight relative to the weight of an equal volume of water, is another important physical property. Color, luster, and the manner in which minerals break — either fracturing or forming cleavage planes — are terms frequently used in describing minerals.

Coal Was Formed from Luxuriant Land-plant Growths.

Today a brownish-black substance known as "peat" is being formed in bogs where plants grow luxuriantly and partially decay as their dead remains fall into the water. Thus peat beds forty feet thick have been formed.

Peatlike deposits are then changed into brown lignite by moderate pressures resulting from layers of sedimentary rock formed over them. In this process water, marsh gas, oxides of carbon, and other gases escape as the plant compounds are decomposed. Lignite, in turn, loses gases as it is subjected to greater pressure to form bituminous (soft) coal. Soft coal is further decomposed as it is subjected to greater pressure, so that the resulting product is nearly pure, hard, glassy carbon called "anthracite," or hard coal. Some deposits of anthracite have been so compressed and heated that they have been changed into an incombustible form of carbon which is called "graphite."

The large coal beds were formed about 250 to 300 million years ago from much more luxuriant vegetation than is found in our present swamps and peat bogs. This vegetation, consisting of huge growths of ferns, horsetails, mosses, and other plants now extinct, must have grown in warm swampy regions. It is possible that the carbon dioxide content of the air was much higher when these plants were growing than it is today.

Coal deposits have been found widely scattered, but the most valuable ones are located in North America. No doubt this important natural resource has greatly contributed to the present advanced position of the United States. Coal deposits representing all of the different stages of their formation are found in the United States. Extensive coal deposits in the eastern Ohio and western Pennsylvania fields are bituminous in nature, but farther east the folding of the mountains as they were lifted up changed these deposits to the finest anthracite coal in the world. Still farther east in the Adirondack Mountains, so great were the forces brought to bear that graphite was formed from similar coal deposits of a different age.

It is not unlikely that coal beds are being formed even now on a small scale in such places as the Great Dismal Swamp, covering fifteen hundred miles in the southern part of the United States, and in the extensive swamp lands near the equator. It is estimated that it would take about four hundred years or more to produce a layer of coal one foot thick. Some of the individual coal layers in the Mammoth Bed of Pennsylvania are from fifty to sixty feet thick.

Petroleum, Natural Gas, and Asphalt Were Produced from Marine Organisms.

Petroleum was used by the ancient Babylonians in their buildings, the Romans used it in their lamps, and the Egyptians embalmed their dead with it.

Inasmuch as practically all petroleum deposits have been found in

sedimentary rocks of marine origin, it is believed that they originated from marine plant and animal life. In the Galician petroleum fields the abundance of fossil fishes indicates the probability that this petroleum was formed from fishes. Deposits in the Caucasian fields were probably formed from mollusks, while the unusually high iodine content of the brines from the oil wells in southern California point to seaweeds as the origin of these petroleum deposits. (During World War I seaweeds were burned in order to obtain the iodine which they extract from sea water.)

It has been suggested that petroleum deposits resulted from inorganic chemical reactions or from algae and diatoms which constantly rain down on the ocean floors from their breeding-grounds in the surface.

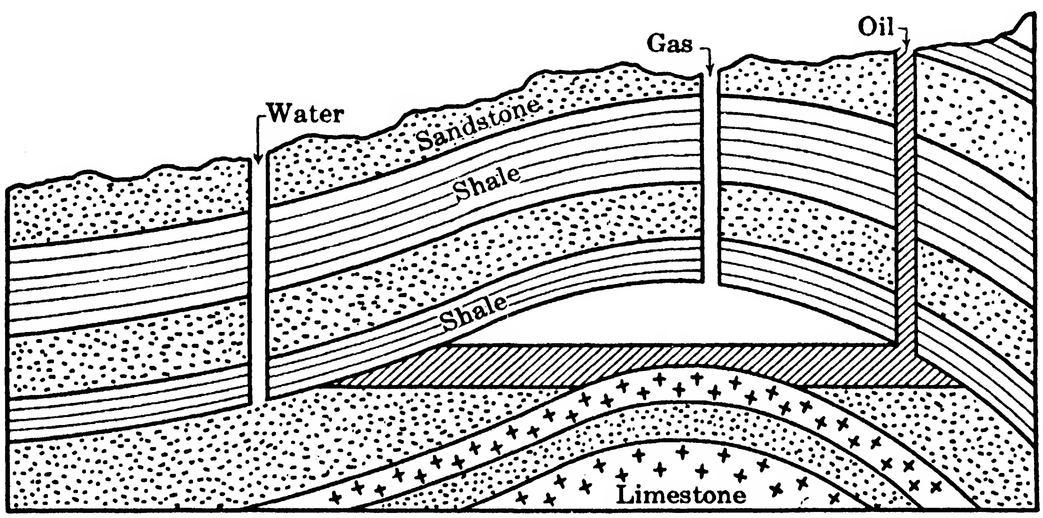


FIG. 58. This diagram of a dome-like formation shows the proper locations for gas or oil wells.

However, most scientists agree on an organic origin, although it is uncertain in what manner natural gas, petroleum, and asphaltum were produced from these organic bodies. Perhaps bacteria played an important role, and it is quite possible that heat produced by slow oxidation or other chemical reactions, and pressure produced by superimposed layers of sedimentary rock aided in their transformation. Once formed, oil and gas would migrate through porous layers of rock, always moving upwards because of their low density, until they were trapped beneath an impervious stratum of clay, where a reservoir would thus be formed.

Modern Oil-prospecting Is Quite Scientific.

The knowledge of the type of geological formations which are likely to contain oil enables the oil geologist to predict many oil discoveries, although "wild-cat" (*i.e.*, unscientific, "drill-and-see") wells often bring in equally important new fields because the knowledge of forma-

tions far below the surface is very imperfect. Some of the most important oil deposits have been discovered in domes of hard, impervious rock which lie above the known sands, where the oil collects as it seeps up from below.

The accompanying diagram shows the proper place to drill a well in a dome in order to have it self-flowing. If the well is drilled at other positions above the dome, gas alone will be obtained, or water may be obtained if it underlies the oil deposit.

STUDY QUESTIONS

1. Account for the different types of coal.
2. Account for the occurrence of heavy minerals in high mountains.
3. List the metals first used by man and explain why these happened to be the first ones used.
4. List four important salts found in nature and give two uses of each.
5. What is the probable source of petroleum and natural gas? Give the reasons for your conclusion.
6. Why are precious stones "precious"?
7. What natural processes have concentrated ores from igneous rocks?
8. Why is salty water often found in oil and gas wells?
9. Is it probable that coal beds are now in the process of formation?
10. What is a jewel?
11. What is an ore?
12. How are veins formed?
13. List some of the varieties of quartz.
14. How are minerals identified?
15. What processes segregate minerals? Give an example of a mineral segregated by each process.
16. For what minerals is the United States dependent upon other countries?
17. What minerals occur abundantly in the United States?

UNIT III

SECTION 9

LIFE IS INTIMATELY CONNECTED WITH CHANGES IN THE EARTH'S SURFACE

Where there is no vision, the people perish.
— Proverbs 29:18.

What shall it profit a nation to gain all the gold in the world and suffer the loss of its soil? — Walter G. Lowdermilk.[1]

Introduction.

The natural endowment of the United States is unrivaled among the nations of the world.

One of the largest of the favorable climatic regions is found in the United States. Almost one fourth of the land suitable for cultivation within the temperate zones lies within the boundaries of continental United States. This Section presents a "get-rich-quick" version of this "paradise lost."

The average uninformed person is likely to consider soil as just plain dirt, not realizing that it is the connecting link between the living and nonliving world. The early pioneer, confronted by seemingly inexhaustible resources of plant and animal life, killed huge herds of buffalos for their hides, ruthlessly cut down the world's greatest forests and burned the wood to obtain charcoal or wood ashes, as if these natural resources were man's worst enemies. Sod which had been thousands of years in the making was plowed up with considerable difficulty; and as soon as a piece of land was denuded of its soil, the plows moved on to new virgin territory. By this time, however, the machine age had multiplied man's destructiveness a thousandfold, so it was not long until the scene of the marvelous golden wheatfields in the Middle West became the desolate graveyard of the machines which made the wheatfields possible and the dust bowl witnessed the exodus of some of our best citizens, who had unwittingly helped to bring about the permanent loss of an alarmingly high per cent of the soil which is our priceless heritage.

[1] U. S. Soil Conservation Service.

Land Plant Life Requires Moist Soil.

Plants must have soil into which they may send their roots for anchorage and from which they may secure the water and soluble minerals essential to their growth. Soil is therefore the most important geological product that is essential to life.

Soil Is a Product of Erosion or Volcanic Action.

Most of the soil is produced from rocks by the various processes of erosion. They are first broken into small pieces by the various disintegrating agents. Plants could not grow, however, even in finely powdered

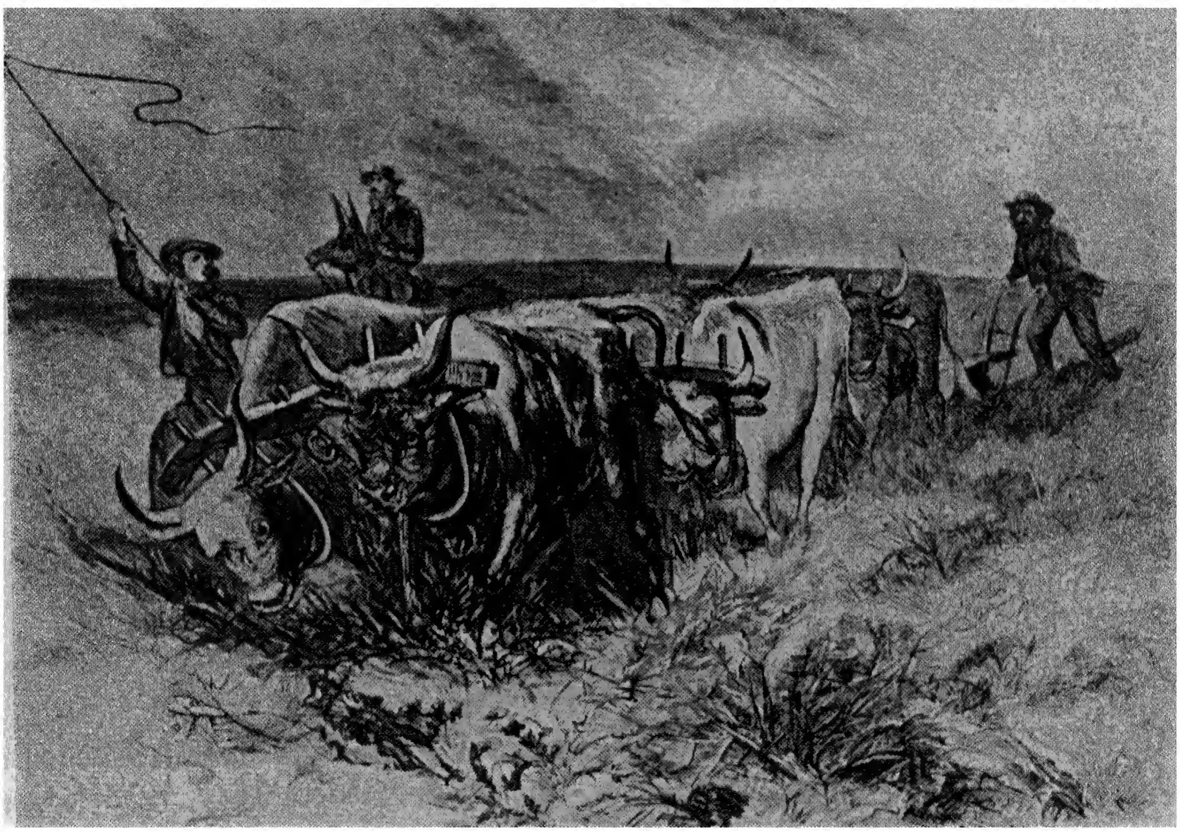


FIG. 59. Plowing on the prairies beyond the Mississippi. (Sketched by Theodore R. Davis.) Six strong oxen were required to pull this plow which is turning over the thick virgin sod of the Great Plains. The pioneer's plow destroyed the luxuriant tall grasses of the Great Plains where the buffalo grazed. (Culver Service, New York.)

rock. Chemical changes must take place in the disintegrated rock before it is suitable for plant growth. Oxygen and carbon dioxide of the air, supplemented by other substances, such as nitric and sulfuric acids, which are produced in the air by lightning, volcanic activities, etc., decompose these rocks.

Even then the decomposed rock particles will not support plant growth. Nature's chemists, the bacteria, must now go to work. Microorganisms can live and multiply in water. Some of them can live without oxygen. Some of them liberate sulfur from the compounds, others

act on petroleum, and still others carry out many different kinds of chemical changes. Good soil contains from one-half million to ten million bacteria per gram. Some of these bacteria take nitrogen from the air and change it into compounds essential to plant growth, while others carry out other changes that provide necessary plant foods.

Plants are thus enabled to grow. As they grow and die, considerable amounts of plant matter such as leaves, roots, and stems accumulate. Bacteria and fungi bring about the decomposition of this organic matter, and the soil is improved with each new crop of plants.

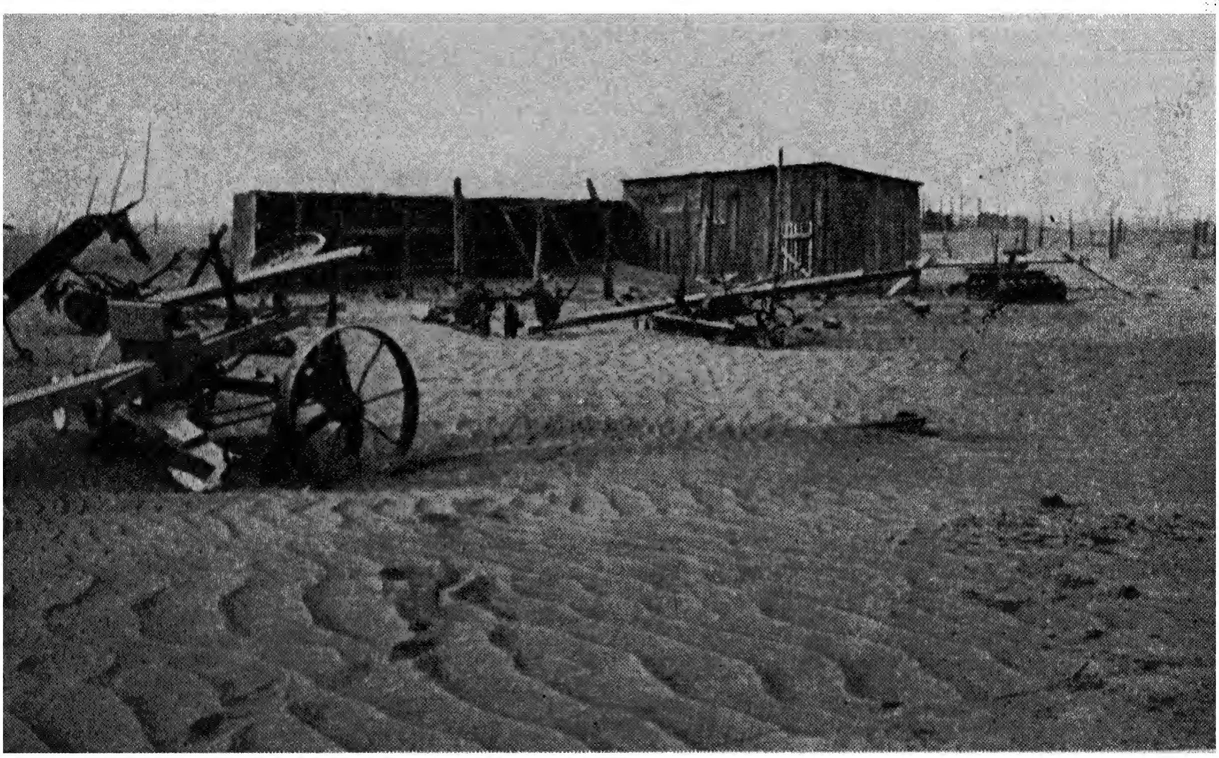


FIG. 60. These farm implements should never have been used because they destroyed a naturally rich grazing area. Mills, New Mexico, May, 1935. (Courtesy of the Farm Security Administration. Photograph by Lange.)

The soil must be kept porous to enable roots to penetrate it. Earthworms eat decaying vegetable matter mixed with soil particles, which are then excreted. The total amount of such castings would amount to twenty tons per acre in one year. The worms penetrate the soil to a depth of five or six feet and thus loosen it up as they form their burrows and enrich it with decaying plant materials. It has been estimated that an acre of healthy soil contains 1,500,000 earthworms, which are equivalent to several skilled gardeners and several tons of rich manure each year.

Many of the higher animals supplement the work of the worms by burrowing into the soil to form their homes. It takes such a long time to produce good soil that man should conserve it as one of his most valuable natural resources.

Our Farm Lands Are Headed for the Sea.

Someone has said that "dictatorship, rather than democracy, has characterized civilized man's attitude toward nature during many ages in the past." Instead of cooperating with nature, we have tried to impose our imperious will; but nature, acting slowly but surely, continues to work in accordance with laws that cannot be changed at will.

For example, the Europeans came to North America as ruthless conquerors, exploiting its rich natural resources and its native population, taking what they wanted, and destroying the rest. They cut down

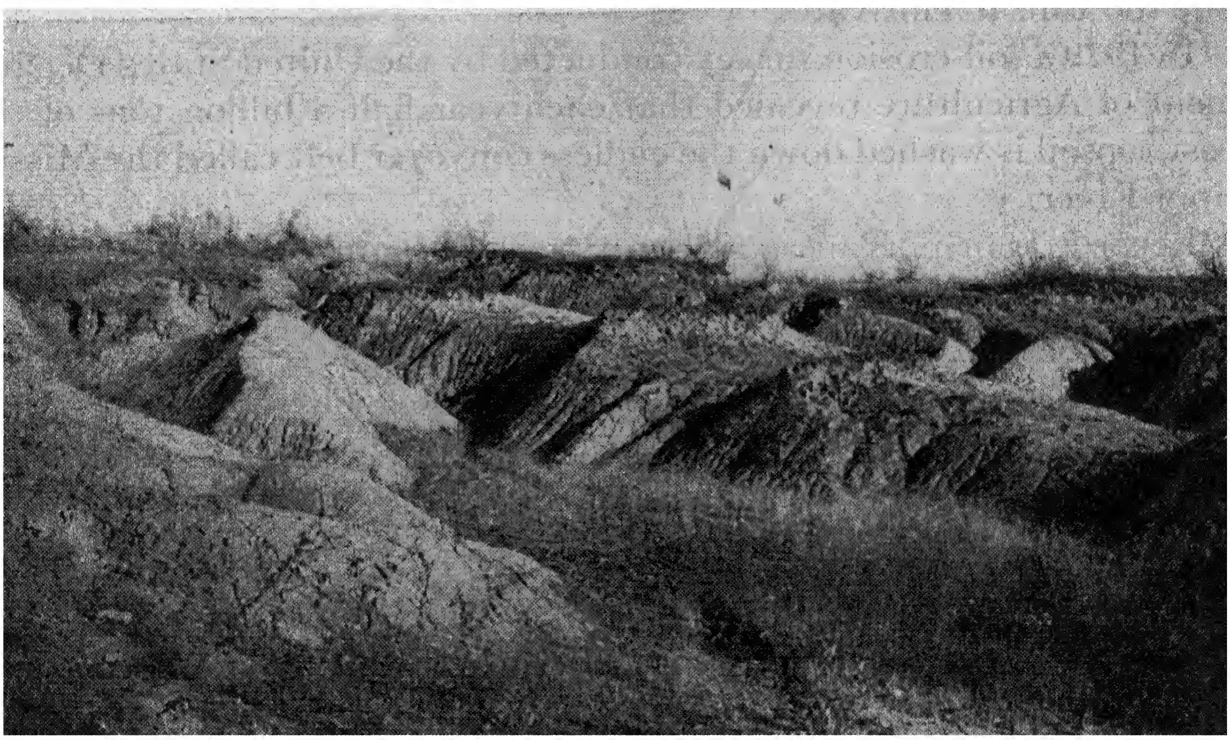


FIG. 61. Soil erosion on a Brown County farm. (Courtesy of the Farm Security Administration. Photograph by Jung.)

and burned forests to provide fields for crops and pastures for animals. They drained swamps and lakes to make available the rich land at their bottoms. It is not until recently that man has begun to see that he is losing some of his most precious resources because he has failed to study the ways of nature and has failed to seek nature as an ally. Man has tried and is still trying to force nature to do his will and has failed because of his ignorance.

When the natural processes of erosion are disturbed, soils, which took centuries to deposit, may be removed in only a few years. This process is called accelerated erosion.

If our soil continues to be carried away at the present rate, our huge dams and reservoirs will become useless within a hundred years; Mead Lake, impounded by Boulder Dam, will fill up.

The National Resources Board estimates that crops and grazing remove 19,500,000 tons of minerals from the soil each year, but that erosion and leaching remove 117,000,000 tons during the same period. The Board estimates that 3,000,000,000 tons of solid soil materials are washed from our farms each year. If we could locate a large soil deposit somewhere and transport it back to our farms by railway trains, it would require one train per minute, each train nearly a mile long, to haul back the soil to replace that which is being lost by erosion.

Mark Twain once said concerning the Missouri River, an important tributary of the Mississippi River, that it was "too thick to navigate, but too thin to cultivate."

In 1929 a soil-erosion survey conducted by the United States Department of Agriculture revealed that each year half a billion tons of the best topsoil is washed down the endless conveyer belt called the Mississippi River.

Records kept in Kansas since 1931 show the following results for a five-year period:

Type of Surface	Per Cent of Water Absorbed	Tons of Soil Lost per Acre	Per Cent Slope
Native grass sod .	99.95	0.013	5
Tilled soil . . .	82.50	13.1	5

On an 8 per cent slope the measured loss on a tilled field during a one-inch rain was 19.5 tons. A California farm on a hillside lost three inches of soil in one cloudburst.

A government survey shows that erosion has practically ruined 50 million acres of once fertile land and that 100 million acres of cultivated land, which is equivalent to the land area of the states of Illinois, Ohio, North Carolina, and Maryland, are being depleted of productive soil at an alarming rate.

H. H. Bennett, Chief of the Soil Conservation Service, testified before a congressional committee in 1935:

> We mapped 70,000 acres formerly cultivated, reduced to largely worthless gullied land. Much of it was the best type of soil in southern Georgia. Some of the gullies are the deepest I have ever seen. The largest of them, locally known as Providence Cave, is near Lumpkin, Georgia. . . .
>
> Last year I talked with a gentleman who went to school in a schoolhouse that stood in the center of Providence Cave. If the schoolhouse were there now it would be suspended 200 feet in the air. It has toppled into the gully, and along with it has gone a tenant house, a barn, a church, and most of a churchyard with fifty graves.

Providence Cave is said to have been started about 1895 from the roof drip of a barn.

Soil Can Be Conserved Only by Conserving the Agents That Built It.

The agents of erosion which brought about the initial disintegration and decomposition of rock materials can quickly remove the fertile soil from a given land area. Floods remove tremendous amounts of soil from the lands only to deposit it on other lands. Running water is even more disastrous than floods in removing good soil. Winds blow the soil away when it is dry.

FIG. 62. Destructive logging followed by fire has completely destroyed this forest, and soil erosion has started. This area was later included in one of the national forests of Colorado. (Courtesy of the U. S. Forest Service.)

When forests are cut down on watersheds, water is no longer detained but runs off quickly, robbing the land of its precious soils and forming flooded streams that continue their costly path of destruction down to the oceans. Semiarid lands are quickly ruined by plowing them up and planting grain, for the protective sod no longer soaks up water to store for dry spells. Soon a drought comes, and the winds blow the soil away. Hills must be kept covered with vegetation to prevent the rapid formation of deep gullies that will quickly ruin a good pasture land.

Loss of soil can be prevented only by avoiding such overexploitation of the soil as overcutting of forests, overgrazing of range lands, and overtilling of fertile lands. The past few years have witnessed an aggressive attack on this problem. Thousands of dams have been

built to check the formation of deeper gullies and to collect silt that would otherwise be washed away. Natural vegetation has been restored, and increased vigilance against disastrous forest fires has been established.

As one passes through the great redwood empire of California and sees the stumps of huge forest trees which have been cut down, he questions the wisdom of such ruthless destruction of trees that required hundreds and thousands of years to grow. The even more irrevocable loss of soil does not disturb the average man because it usually takes place more slowly and less noticeably. However, trees will return in a few centuries, but it requires thousands and thousands of years to produce soil.

The United States must not repeat the error that the Chinese made by deforesting and overtilling their fertile hillsides and thus providing conditions for a rapid run-off of heavy rains and melting snows. News items of very disastrous floods in China, covering thousands of square miles and driving hundreds of thousands of people from their homes, are a matter of almost yearly occurrence, while the very color of the Yellow Sea is a reminder of the soil which the Yangtze and Yellow rivers have carried to it.

Terracing is being introduced to provide flat planes for clean-cultivated crops, the steep risers being protected by sod or other soil binders. Strip-crop cultivating is a variation of the terracing idea, in which strips of crops like sorghum or millet, which provide soil-holding mats of roots, are planted in concentric rings around a hill between the clean-cultivated crops. Contour furrowing is replacing straight furrowing on slopes. An effort is being made to retire poor farm lands from production to prevent erosion.

The United States Government Is Now Engaged in Many Conservation Projects.

Space will not permit the modern story of "Paradise Regained." All we can do is to point out a few of the results being obtained now that planning has come to be recognized as a function of a democracy and cooperation of an enthusiastic citizenry has put these plans to work.

The waters of thirty-one states mingle in the Mississippi River, "The Father of Waters," each of whose frequent floods has destroyed property valued at hundreds of millions of dollars. Today the Mississippi River is hemmed in by 1825 miles of levees, twenty-one feet in height, that cost over one billion dollars. The Colorado River has been tamed by the construction of Boulder Dam. The great dams of

the Tennessee Valley Authority and those on the Columbia River represent efforts of men to cooperate with each other and with nature.

The Bureau of Reclamation has built 165 dams to irrigate 4,000,000 acres of arid and semiarid land and at the same time prevent floods and generate power.

The Central Valley Project in California is designed to prevent some 200,000 acres of rich lands from becoming a desert because of the lowering of the water table by extensive irrigation.

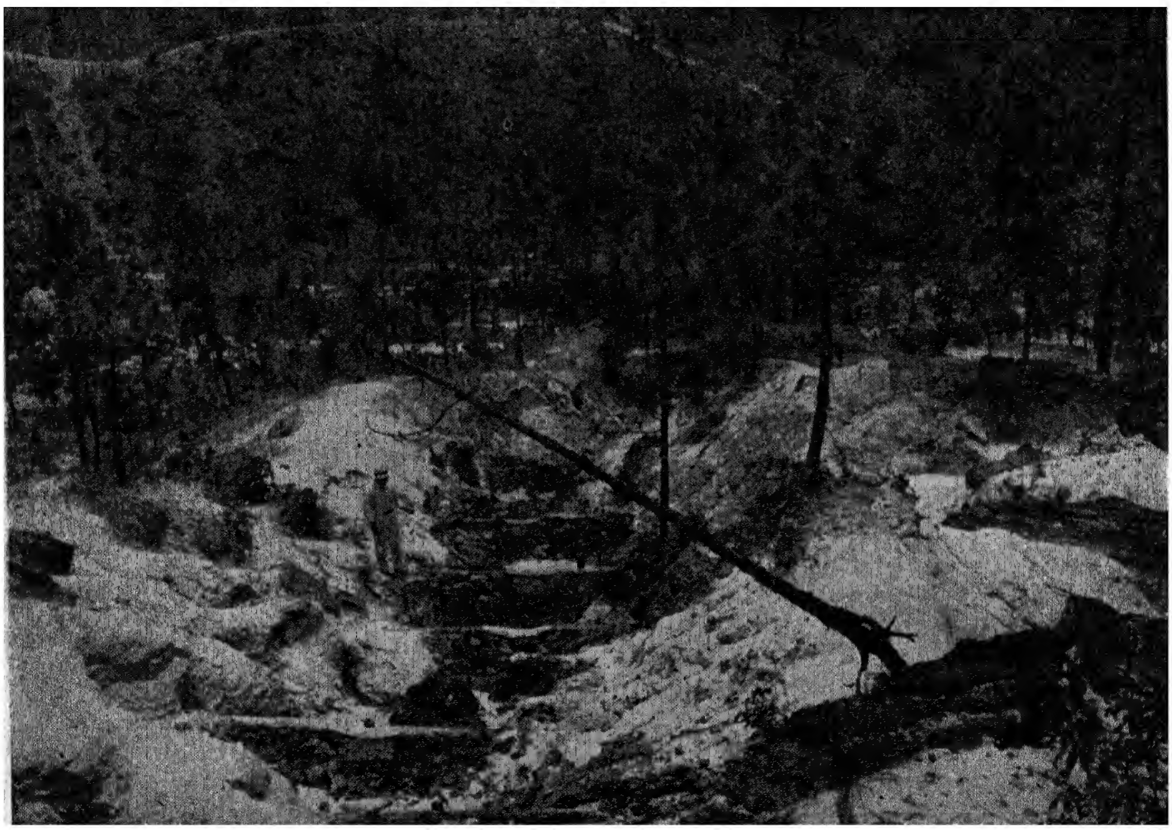


FIG. 63. Sandhills Agricultural Project of South Carolina. (Resettlement Administration photograph, by Mundans.)

The United States Government owns 750,000,000 acres of land, including valuable national forests, which it is wisely administering from the point of view of conservation.

The Taylor Grazing Act of 1934 established the United States Grazing Service, which supervises the conservation of 142,000,000 acres of public grazing-lands.

The Department of the Interior is carrying out soil conservation work on 285,000,000 acres of land, equivalent to one seventh of the area of the United States.

The Civilian Conservation Corps, the Resettlement Administration, and many other government agencies have cooperated in a far-sighted program of conservation that demonstrates that democracy will and does work.

Man's Past Successes Have Been Those of Adaptation.

The freedom of which man likes to boast has been and still is to a large extent merely the freedom to choose between adapting himself to his world or perishing.

The listless, ambitionless, naked men who live near the equator are the products of their environment. Here the monotony of seemingly endless days of merciless heat and daily rains leads to inaction. The surrounding jungles are practically impassable; and men are in constant combat with deadly diseases, insects, and beasts.

A little farther from the equator man can live with ease. There is still sufficient heat to lead to inaction, but little work is required.

Clothes are unnecessary. Palm-leaf shelters are adequate protection against rains. Land need only be cleared and planted, and nature does the rest in providing food. Even this little effort is unnecessary except in the more densely populated regions. Here man is held to a low level of existence by the superabundance of sun, rain, and plant life. There is nothing to work for — why work? [1] On the fringes of the jungles live great masses of people — the Javanese, Indians, and Chinese, who live in subtropical lands which, because of the suitability to rice culture, will support as many as a thousand people per square mile. But here work is required, diseases rage, and only the fittest survive. Here man has learned to live in groups, but advances come very slowly. Man power is cheap, and life is not highly valued.

Then there are the great grassy plains unfit for anything but pasture. The inhabitants of these great sections of Africa and India are wandering herdsmen. Certainly these are not conditions for the development of civilization.[2]

Then come the great deserts such as the Sahara, the Gobi, the Arabian, the Kalahari, and even the Mojave. Intensely hot in the day and bitterly cold at night, they do not offer comfort. The desert vegetation with its spikes, thorns, and hard bark makes food difficult to obtain. Here conditions are too rigorous for man to develop a civilization. There is an irresistible charm about the desert, but it is home only to a few unsocial people and nomads who have never known a different life.

The edges of the deserts support some of the most primitive men in

[1] People will put up with an enormous amount of inconvenience rather than go to the trouble of doing the thinking necessary to remedy the situation. Man is held to a low level not because of adverse conditions but because this low level is easy to maintain.

[2] The primary stimulus which initiates a civilization is a challenge. The extent to which a civilization once initiated thereafter develops depends on a balance between the nature, strength, and continuation of the stimulus and the material obstacles to be overcome. A civilization enters upon a static period when the two balance.

existence today. The Bushmen of Africa and Australia practically reincarnate the Stone Age for us, turning back the pages of time just as the light from distant stars shows us what they were like a million or so years ago.

Then there are the extensive polar regions, where man has been able to live only by making tremendous efforts to adapt himself to his environment. He must make his home out of ice. He is limited almost entirely to animals for his food and clothing. He has little freedom and must eat food when it is available and starve when it is not.

Man's Recent Successes Are Those of Overcoming Environmental Limitations.

Some of our great civilizations have developed in the temperate zones, with their warm and cold, wet and dry, seasons. Here people gathered in large numbers in the fertile valleys, which offered food in exchange for work. Here man required substantial clothing and housing. Here conditions led to activity and yet left time for dreams. Here man began to seek to control his environment by use of fire to heat his homes and by the development of means of transportation to bring foods, textiles, and useful objects from all over the world. Here man sought to control the rivers which nourished his crops. Here civilizations developed; and here, at last, man began to create a new environment.

At last man has had a taste of freedom. This romantic story of man's conquering his environment through a study of the properties of the materials nature has furnished him is just as interesting and fundamental as the stories of the universe and the nature of the earth which we have just finished.

This is the story that is told in the remaining units of this text — a story that is yet far from complete. We have not yet experienced the full measure of freedom which Science and technology are now making possible, and it may be that we will experience several different types of "dust bowls" before we learn how to control the freedom we have yet to win. The dust bowl was an excellent example of ignorance in action and of rugged individualism in an age when both ignorance and individualism, aided by the power of the machine, are capable of destroying many of man's most priceless heritages. You are about to study the discoveries that may give man his freedom. In studying this story, try to formulate plans in your own mind by which the new responsibilities that freedom always brings may be borne in a democratic society.

We shall see that this taste of freedom has not been followed by the

full experience of freedom which is now possible, because man has not been able to evolve an economic system in which *needs* rather than private profits control production and distribution.[1]

STUDY QUESTIONS

1. Outline briefly the steps involved in the evolution of soil.
2. Why does it take so long to evolve good soil?
3. Why are the crops produced in many places in the United States giving lower yields per acre from year to year?
4. Outline the functions of bacteria in soil production.
5. What are the causes of soil erosion?
6. Outline the most important methods of combating soil erosion.
7. Why has man been content with a low level of existence in the tropics?
8. What has been the secret of man's success in past ages?
9. What is meant by saying that man has had a taste of freedom?
10. Why have civilizations developed to the highest extent in temperate zones?
11. In what respects is the United States richly endowed in natural resources?
12. Give examples of the way in which the United States has squandered its natural resources.
13. Why has the United States not conserved its natural resources?
14. Has the power made possible by Science and technology been used for the general welfare?

[1] If a nation can, in war time, engage in an all-out production of things people do not want (*e.g.*, bombs), which we deliver free to people we do not like, why can't we in peace time engage in an equally unlimited production of things people *do* want, which we will deliver free or at nominal cost to ourselves or other people we do like?

*

UNIT IV

MAN HAS APPLIED HIS KNOWLEDGE OF PHYSICAL PROPERTIES AND PHYSICAL CHANGES TO OVERCOME MANY PHYSICAL LIMITATIONS

INTRODUCTION TO UNIT IV

Matter may exist in the solid, liquid, and gaseous states. Any change from one state to another, such as the freezing of water, is called a physical process. Such changes are always found to be accompanied by a gain or loss of energy, often in the form of heat. Repeated observations of the physical properties and changes of matter have resulted in the development of numerous hypotheses, theories, and laws. This unit will consider the nature of heat, the laws of physical processes, and the kinetic-molecular theory which explains them. The applications of these generalizations to new situations, with the resultant valuable processes and devices which aid man to adapt himself more successfully to life on the earth, will then be studied.

UNIT IV

SECTION 1

MATTER IN THE GASEOUS STATE EXHIBITS MANY INTERESTING PHYSICAL PROPERTIES

Introduction.

It seems almost incredible that the idea of the existence of matter in the gaseous state was unknown until the past few hundred years. Man lives in a gaseous ocean and breathes air which is a mixture of gases.

There Are Two Types of Properties.

Matter is described in terms of its properties. There are two types of properties, *physical* and *chemical*. *Physical properties* are those whose manifestation appears to be unaccompanied by any change of composition. Thus the freezing- and boiling-points [1] of water are physical properties. The color and crystalline form of sugar are other examples of physical properties.

Such properties as color, odor, taste, density, solubility, hardness, ductility, expansibility, melting- and boiling-points, heat and electrical conductivity, and specific heat are physical properties.

The second group of properties, *chemical properties, are those which express the capacity of a material for being transformed into other materials.* Thus the ability of gasoline or of wood to burn, or of iron to rust, is a chemical property.

Chemical properties tell with what a material reacts (if the change involves a reaction with other substances), *under what conditions it reacts, what materials are produced by the change, how much of the materials are involved in the change, and how much energy is used up or evolved in the process.*

A Knowledge of the Properties of Matter Is Important.

Scientists spend a great deal of time in observing and measuring the properties of matter. The properties of matter determine its

[1] The freezing- and boiling-points of liquids are those temperatures (points on thermometers) at which liquids freeze or boil, respectively.

occurrence, i.e., where, in what form, and how abundantly it is found; thus gold is found uncombined with other elements because it does not readily combine with them. Gold is found in the bottom of a pocket of sand or gravel because its density is greater than that of sand or gravel.

The properties of materials also determine their *uses;* thus hydrogen is used for airships because it is the lightest gas known.

To the scientist the *chief value* of knowing properties, however, is that through them we establish *the identity of or the difference between materials.* Fortunately, only a few properties need to be accurately known for this purpose; *when two materials agree in a few of their properties, they agree in all.* The minimum number of properties has not been determined, so mistakes are frequently made due to a lack of knowledge. Thus counterfeit coins may look exactly like the original ones, but experienced people recognize them by their weight or their ring when dropped on a table.

Matter Exists in the Gaseous, Liquid, and Solid States.

The different states of matter — gaseous, liquid, and solid — are called physical states because they differ in physical properties only.

Van Helmont (1577–1644) invented the term "gas" to describe different substances that resembled air in form. GASES *have no defining bounding surfaces and no definite volumes except those of the containing vessels; they completely fill any container in which they are placed.* LIQUIDS *have a definite volume but no definite shape; they go to the bottom of containers in which they are placed and take the shape of that portion of the container they fill.* SOLIDS *have definite shape and volume; they go to the bottom of the containers in which they are placed but do not take the shapes of the containers.*

Gases produce uniform pressures on the walls of containing vessels. They are much more compressible than liquids, whereas liquids are more compressible than solids. Gases are likewise more expansible than liquids, which in turn are more expansible than solids. Gases mix with other gases with which they are placed in contact. Some liquids mingle in all proportions, whereas others intermingle to a limited extent only; and solids intermingle very slightly when placed in contact with each other.

Gases, under ordinary pressures, are of much lower density than liquids or solids.

Thus we see that gases, liquids, and solids differ in such physical properties as *expansibility*, *compressibility*, *diffusibility*, *volume*, *shape*, and *density*.

The Properties of Gases Have Many Practical Applications.

Robert Boyle (1627–1691) proved that air is a material and has weight, but he is chiefly remembered for his discovery that *the volume of a given quantity of gas is inversely proportional to the pressure, provided that the Temperature remains constant.* This behavior of gases is called Boyle's Law. This law is simply the statement of a property of gas already familiar to you (*i.e.*, its compressibility), for everyone realizes that the volume of gas compressed into an automobile tire, for example, depends upon the pressure exerted. If the pressure on a tire is suddenly released, the tire blows out, *i.e.*, the gas suddenly greatly increases in volume.

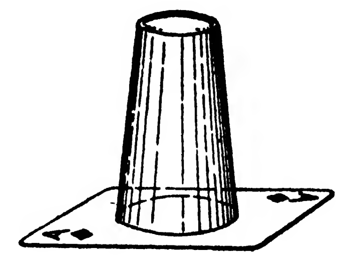


FIG. 64. The pressure of the atmosphere prevents the card from dropping from the glass and thus allowing the water contained therein to pour out.

Man is so well adjusted to life in the atmosphere that he scarcely realizes the pressure which the atmosphere exerts. At sea level, the pressure of the atmosphere is equivalent to the pressure which an ocean of water 34 feet deep would exert. To give an idea of the weight of the atmosphere, it is interesting to note that although the carbon dioxide content of the air is only 0.04 per cent, it is estimated that there are 2,200,000,000,000 tons of carbon dioxide in the earth's atmosphere.

The pressure of the atmosphere is readily shown by the experiment in which a glass filled with water is covered with a card and inverted.

Otto von Guericke (1602–1686), the Magdeburg physicist, invented the air pump, which made it possible for him to evacuate containers. In one of his spectacular experiments he had fifty men tug on a rope attached to a piston in a cylinder and then sent them sprawling by allowing air to enter the cylinder. His most famous experiment is the one in which he placed two hemispheres together and after evacuating the sphere thus formed showed that several teams of horses attached to each hemisphere were not able to pull the spheres apart because of the enormous pressure of the atmosphere.

The pressure of the atmosphere decreases with an elevation in altitude. The accompanying table shows how the pressure varies with altitude.

ALTITUDE	PRESSURE (in cm. of Mercury)
Sea level	76.0
500 feet	74.6
1,000 feet	73.2
2,000 feet	70.6
3,000 feet	68.1
4,000 feet	65.6
5,000 feet	63.2
7,500 feet	57.0
10,000 feet	52.0
20,000 feet	35.0
40,000 feet	14.0
60,000 feet	5.0

Pressure Is Generally Measured with a Mercurial Barometer.

Evangelista Torricelli (1608–1647) in 1643, the year after the death of his teacher, Galileo, filled a glass tube, closed at one end, with mercury, immersed it in a bath of mercury, and had the pleasure of seeing the mercury level drop to a height of 30 inches, which his previous calculations had led him to expect it to do. The vacuum left above the mercury in a barometer has ever since been called the *Torricellian vacuum.*

Torricelli's experiments were received with incredulity because they were contrary to the long-accepted teaching of the Greek philosophers that "nature abhors a vacuum." Torricelli died before he could convince people that nature abhors a vacuum only up to the extent of the pressure of the atmosphere. In 1648 *Blaise Pascal* (1623–1662) repeated Torricelli's experiments, using a 50-foot tube and water for his liquid. He found that the water rose in the tube to a height of about 34 feet, which corresponds to 30 inches of mercury, water being about 1/13 the density of mercury.

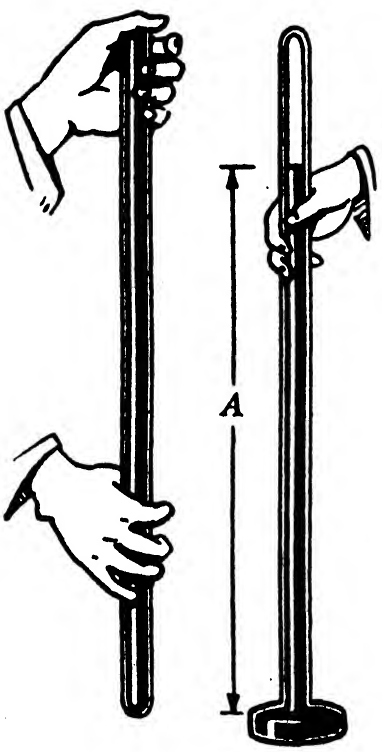


Fig. 65. A simple mercurial barometer.

In 1647 *René Descartes* wrote to Pascal suggesting that the height to which the mercury would rise in the mercurial barometer would be less at higher altitudes where the atmospheric pressure is less. Pascal had his brother-in-law, *Florin Perier*, conduct this experiment for him. Perier took a tube to a mountain top and found that the mercury level was 3 inches lower than at the foot of the mountain. On the basis of this experiment Pascal worked out the use of the barometer for measuring heights above sea level.

Various accessories are added to modern barometers to permit precision in reading the height of the mercury in the tube above the level of the mercury in the cistern, in order to measure the small rise or fall of mercury in the tube in response to slight increases or decreases of the atmospheric pressure. A thermometer is mounted on the barometer because corrections must be made for temperature.

The Aneroid Barometer Is Portable.

The sensitive part of the aneroid barometer consists of a small, airtight, corrugated metal box with the air exhausted and a flexible cover held in position by a spring. Changes in air pressure move this cover in or out, which motion is communicated to a movable pointer

by a system of levers. The whole mechanism can be placed in a case the size of a watchcase and is therefore very convenient for ordinary use.

Pressures of liquids or gases may also be measured with *Bourdon* pressure gauges or with manometers. *Manometers* are bent glass tubes partly filled with some liquid. Manometer tubes with closed ends are used in measuring high pressures, while those with open ends are used in measuring low pressures. The manometer may serve as a barometer if the arm of the bent tube is sufficiently long and is sealed at the end. A Torricellian vacuum must be maintained above the mercury which is used as the liquid in this case.

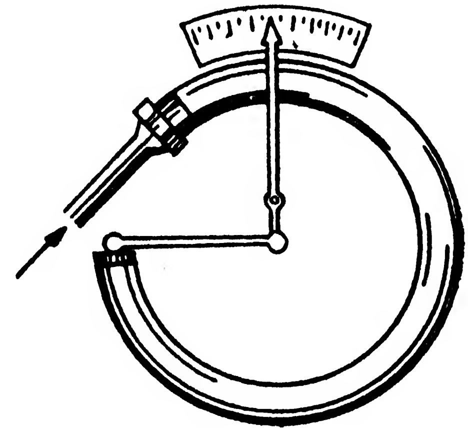


FIG. 66. The principle of the Bourdon gauge.

The *sphygmomanometer*, used by physicians in taking blood pressures, is a special type of manometer. A rubber bag is wrapped around the arm and is inflated by means of a rubber bulb until there are no pulsations felt at the wrist, indicating that the flow of blood has stopped. The pressure thus required to stop the flow of blood is the maximum blood pressure.

Pumps Are Applications of Boyle's Law.

The principle of the lift pump depends upon the fact that the atmospheric pressure lifts the column of water. Inasmuch as the pressure of the column of air cannot support a column of water more than thirty-four feet high, the pump will not lift water more than this distance.

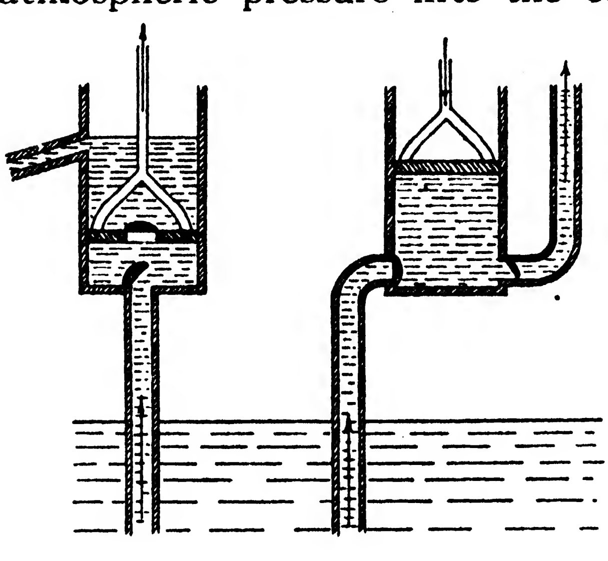


FIG. 67. The lift pump (left) and the exhaust pump (right).

The force pump will force water higher than atmospheric pressure will lift it.

The exhaust or compression pump is similar to that used to pump up tires; it may be used to remove air from a container or to compress air into a container. The heart itself is a pump, with valves to direct the flow of blood in the right direction. Instead of a piston action, the heart contracts and expands and thus pumps the blood.

The siphon is an application of the pressure of the atmosphere.

Charles' Law Deals with Temperature-volume Relationships.

The expansibility of gases is another property of gases stated as a law, named after *Charles*, who first observed that *under constant pressure the volume of a gas is very nearly proportional to the absolute temperature.*

This property is likewise familiar qualitatively, because, as most people have observed, the volume of a gas in a closed container will expand when heated, provided that it is capable of expansion. Thus the sides of a gasoline tin will bulge out and a balloon will swell to the bursting-point as it is heated. The quantitative aspects of this law are not so well recognized, inasmuch as the absolute-temperature scale is unfamiliar. The three common temperature scales are shown in Fig. 68.

It was observed that the volume of a given weight of gas would decrease 1/273 for each degree of decrease in temperature below 0° C. If the temperature were lowered 273° C., the decrease in the volume of the gas would thus produce zero volume if the gas did not condense earlier. (All gases do condense above absolute zero.) This temperature, called *absolute zero*, is the lowest temperature theoretically possible to obtain. It has been approached experimentally within a small fraction of a degree.

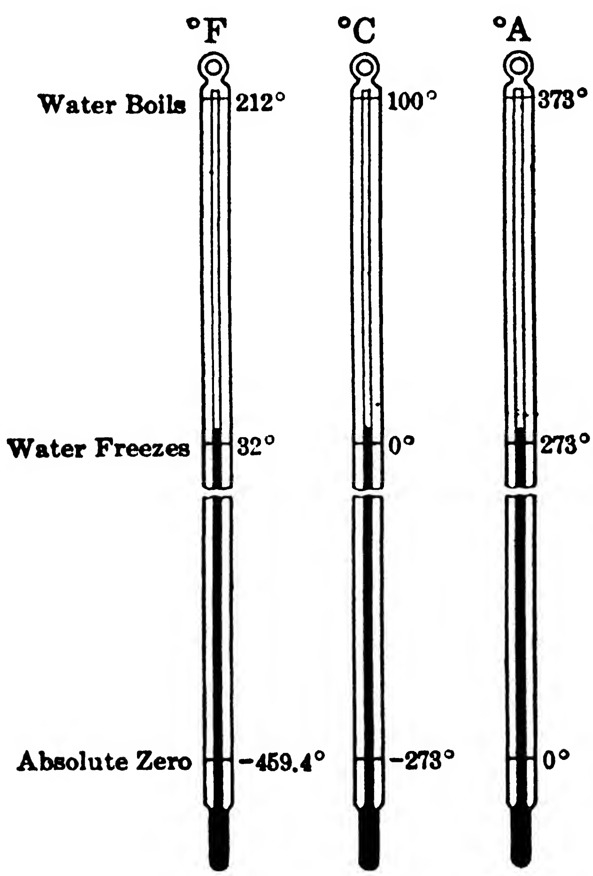


FIG. 68. The three temperature scales.

Standard Temperature.

In making many measurements, the results must be expressed at the same temperature for purposes of comparison. The standard reference temperature is 0° C.

Temperature measurements depend upon the measurement of the amount of expansion of gases or liquids, such as mercury or alcohol, in thermometers. Temperatures may be measured by the electric current produced when one of two metals in contact with each other (a *thermocouple*) is heated. In the case of the *resistance thermometer*, the temperature is measured by the change in the electrical resistance of a coil of wire in response to changes in temperature. Inasmuch as electrical resistance can be

easily measured with great precision, the resistance thermometer is widely used in scientific investigations. Any temperature-measuring device must be calibrated in terms of certain standards; the usual standards for calibrated temperature-measuring devices are the boiling- and freezing-point of pure water, which are always the same at standard pressure. The people of Florence used the body temperature of cows for the upper standard. Later the temperature of the human body was accepted as the standard temperature and called 100°. This was the origin of the Fahrenheit scale, but somewhat fevered subjects must have been used inasmuch as the normal body temperature is usually considered to be only about 98.6° F.

Gases Diffuse Readily.

When gases are mixed, the pressure or the volume of the resulting mixture is equal to the sum of the original pressures or volumes of the original gases, provided that the temperature is kept constant. In other words, they behave just as if they were present alone. Dalton's Law of Partial Pressure states this behavior as follows: *Each gas in an ideal gaseous mixture exerts the same pressure as it would if it occupied the whole space alone.*

The rates at which gases will diffuse in each other depend on their densities. A convenient way to measure the rates of diffusion of gases is to determine the time required for equal volumes of different gases to pass through a small orifice or porous surface. Such experiments have shown that *gases diffuse at rates which are inversely proportional to the square roots of their densities.* This is a statement of *Graham's Law.*

STUDY QUESTIONS

1. Why does the pressure in an automobile tire increase on a hot day?
2. Explain the action of the simple lift pump, and show why it will not lift water more than thirty-four feet above the free surface.
3. Define and contrast the different states of matter.
4. State the laws which deal with the effect of temperature and pressure changes on the volume of a gas.
5. Why does hydrogen gas diffuse more rapidly than carbon dioxide gas?
6. How could you prove that the atmosphere exerts a pressure?
7. How could you measure the atmospheric pressure?
8. Explain the use of a barometer to estimate the altitude.
9. Differentiate between physical and chemical properties.
10. Give several illustrations of each type of property.
11. What are the values of a knowledge of the properties of a substance?
12. State Graham's Law.
13. State Dalton's Law of Partial Pressure and work out an illustration.

14. What is standard temperature?
15. What are the freezing- and boiling-points of water in the three temperature scales?
16. What is the normal temperature of the body on the centigrade and absolute scales?
17. What is the average room temperature (68° F.) on the centigrade scale?
18. What is absolute zero?
19. On what basis was the absolute scale worked out?
20. Give the principle of the aneroid barometer.
21. How would you construct a mercurial barometer?

UNIT IV

SECTION 2

A KNOWLEDGE OF THE PROPERTIES OF LIQUIDS HAS LED TO MANY USEFUL APPLICATIONS

Introduction.

If the temperature could be raised sufficiently, all matter could be changed to the gaseous state. This is the actual condition of the matter in the sun. It is also generally recognized that nearly all solids may be changed to the liquid state by raising the temperature, provided that they do not decompose or sublime first. The great abundance of matter in a liquid state (such as water) and the fact that liquids are more tangible than gases caused some of their properties to be studied thousands of years ago, and several of the applications studied in this Section have been known for a long time.

Viscosity.

Liquids possess the property of fluidity, which is a measure of the ease with which they flow. Viscosity is a universal property of liquids. It is the inverse of fluidity, for it is measured by the resistance to flow resulting from the internal friction of a liquid. The viscosities of such liquids as molasses and tar are high at ordinary temperatures, while the viscosities of water and alcohol are much lower. It is a common observation that tar is heated in order to make it flow readily, and it is a general rule that viscosities of liquids decrease with increases in temperature.

Some liquids have such high viscosities that there is a question whether they are liquids or solids. A true crystalline solid ceases to be crystalline when it flows. True solids are distinguished from highly viscous liquids in that true solids have sharp melting-points and produce characteristic patterns in the X-ray spectrograph. Therefore, glass tubing which will bend out of shape in a few weeks at ordinary temperatures and a paraffin candle which droops in the summer weather are properly regarded as examples of highly viscous liquids.

Lubricating oil is purchased by the S.A.E. number, which refers to the viscosity measured by standard methods prescribed by the Society

of Automotive Engineers in America. The usual method of measuring viscosities is to determine the time required for a liquid to flow through a given tube or orifice at a standard temperature.

A lubricating oil needs to have a sufficient viscosity to maintain a film of oil between the lubricated surfaces. Too low a viscosity results in inadequate lubrication, while too high a viscosity results in needless loss of power due to friction in the oil film itself. Oils used in cold weather should be of lower viscosity than those used in the summer because of the fact that the viscosity increases at lower temperatures, sometimes to the extent that cars cannot even be started.

The viscosity of the body fluids normally remains fairly constant. When a person has a fever, the viscosity of the blood is less, and, other things being equal, it is therefore easier for the heart to pump the blood through the circulatory system.

The viscosity of a liquid has its counterpart in that of gases. Both gases and liquids offer resistance to the passage of solids through them. This resistance, or friction, increases as the velocity of the moving solid increases. It is only within recent years that attention has been paid to the question of decreasing the resistance of the air or water on a fast-moving body. Engineers first became interested in the problem when they sought to increase the velocity of steamships and airplanes. Modern airplanes have been designed to offer the minimum resistance to air. More recently this same principle of streamlining has been applied to railroad trains and automobiles.

Streamlining of bicycles, toy wagons, teakettles, and houses is, of course, merely a fashionable trend in design.

Engineering tests with a modern car have shown the effect of different rates of speed on the gasoline mileage:

20 miles per hour	21.7 miles per gallon
30 miles per hour	19.9 miles per gallon
40 miles per hour	18.0 miles per gallon
50 miles per hour	16.0 miles per gallon
60 miles per hour	13.8 miles per gallon
70 miles per hour	11.4 miles per gallon

A portion, at least, of this decrease in efficiency is due to the increased resistance offered by the air at higher speeds. The resistance offered by liquids is, of course, greater than that of gases, so that steamships have long been so designed as to offer the least underwater resistance.

The resistance to the flow of liquids is well illustrated in a water-distribution system.

The height to which water will rise when in motion depends on the resistance offered by pipes of different diameters. The velocity of the

liquid in the smaller pipes is greater than that in the larger pipes, and the resistance is therefore greater.

Surface Tension.

Liquids also exhibit a property called *surface tension*. This is a force acting at the surface of a liquid which tends to cause the liquid to expose the least possible surface. Water gathers into droplets on dirty or greasy surfaces because of surface tension. In the same way mercury forms drops when it is poured on a surface to which it will not adhere.

When liquids are placed in capillary tubes, surface tension causes them to rise or sink in the tube above or below the level of the surrounding liquid, depending on whether they wet or do not wet the inner surface of the tube. Surface tension may, therefore, be measured by determining the rise (or fall) of liquids in capillaries.

The slender capillaries in plants account to a certain extent for the rise of sap in plants, although evaporation at the leaf end of the capillary is quite important. The fibrous nature of blotting paper makes it absorbent because the spaces between the fibers act as capillaries. Paper intended to be used with ink must be sized to prevent the spread of the ink due to this capillary action. Sponges and towels absorb water because of capillary action. Soils are cultivated in order to increase the size of the capillaries and at the same time decrease the number of capillaries which would draw water to the surface where it would be lost by evaporation. Careful cultivation is therefore very essential to plant growth during dry periods.

Liquid Pressure.

The pressure exerted by a liquid is equal to the sum of the external pressure on it and the pressure due to its own weight. Pressure is defined as the force per unit area.

The transmission of external pressure throughout a liquid was studied by the brilliant French experimentalist, *Blaise Pascal* (1623–1662). Pascal's law is stated as follows: *Whenever pressure is exerted at any part of a liquid, this pressure is transmitted to all parts of the liquid, and the transmitted pressure is the same at all points as the original pressure.*[1] Pascal also showed how this law could be applied to obtain large forces in the hydraulic press.

In this press there is a multiplication of the force in the ratio of the areas of two pistons. Thus a force of one pound on one piston would produce a force of six hundred pounds on a second piston having six hundred times the area of the first one.

[1] This law also applies to gases.

The hydraulic press is used for many purposes in industry: it is used to compress cotton or paper into bales, to extract the oil from cotton seed, and in machines to test the strength of various materials. Hydraulic automobile brakes and lifts are similar in principle to the hydraulic press.

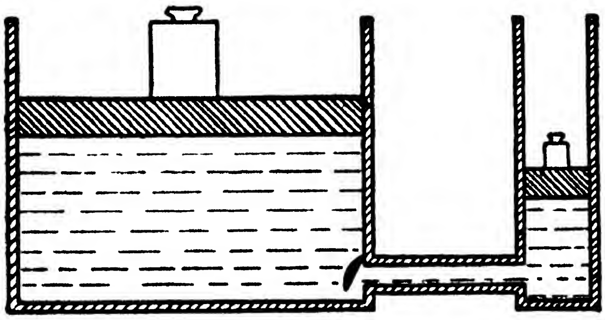


FIG. 69. The hydraulic press principle.

Archimedes' Principle of Floating Bodies.

Pascal's observations concerning liquids were the most important ones made since *Archimedes* of Syracuse (287–212 B.C.) discovered the principle, known by his name, *that when a body is immersed in a liquid (or a gas) the loss in weight of the body will be equal to the weight of the liquid (or gas) displaced, and the body will be buoyed up by a force equal to the weight of the liquid (or gas) displaced by it.*

The story of this discovery is that Archimedes was given the problem of determining whether or not *King Hiero's* golden crown had been alloyed with silver. Archimedes was bathing one day and noticed that he displaced water equal in volume to his own body. At once he saw that the lighter alloy of gold and silver would displace more water than an equal weight of pure gold.

Why do bodies float when immersed in a liquid? What causes a diver to reach the surface of the water again? The pressure exerted by a liquid acts on all parts of the surface of a submerged body and always at right angles to it. Inasmuch as the pressure increases with depth, there is a greater pressure at the lower surface of the body than at the upper surface. The difference between these pressures causes the liquid to exert a buoyant force. The water in the Great Salt Lake has a greater buoyant effect than that of fresh water because its greater density produces a greater pressure at any given depth.

Liquids show a wide range of density [mass (weight) per unit volume]. The densities of a few common liquids are given in the following table:

SUBSTANCE	GRAMS PER CUBIC CENTIMETER
Gasoline	0.66–0.69
Ethyl alcohol	0.79
Olive oil	0.98
Water	1.00
Chloroform	1.48
Carbon tetrachloride	1.59
Bromine	2.93
Mercury	13.55

The sink-and-float process for the removal of unwanted materials from minerals and from coal depends upon the use of liquids of such a density that one ingredient in a mixture will sink and the other one will float. This process, worked out by the E. I. du Pont de Nemours Company, offers many economies in cleaning coal and concentrating ores. Do not confuse this process, technically known as "beneficiation," with ore flotation which is based on surface tension.

Archimedes' principle is applied in measuring the density of solids and liquids. One application of this principle is found in the hydrometer. Hydrometers are floating vessels adjusted for certain ranges of density. They are buoyed up in proportion to the density of the liquid measured. The percentage of alcohol in water can be determined, for example, by the hydrometer, because the density of mixtures of alcohol and water decreases with increasing concentrations of alcohol. Similarly the density of sugar solutions is measured with a special type of hydrometer.

Among the many special uses for hydrometers, the battery-tester is one that is very familiar to many people. It is based on the fact that the density of the sulfuric acid solution in a storage battery decreases as the battery is discharged.

Hydrometers are also used in testing milk and fuel oil and in testing the purity and concentration of many solutions used in chemistry and industry.

Submarines are able to float or submerge by changing their weight. Water is allowed to enter a compartment in the submarine to add to the weight when it is desired to submerge it. When it is desired to bring the submarine to the surface again, it is raised by forcing the water out of the compartment with compressed air.

The density of a solid may be determined by weighing the solid in the air and then weighing it in water. The difference between the two weights represents the weight of water displaced by the body, that is, the weight of an equal volume of water. The ratio of the weight of the body in air to the weight of an equal volume of water is the density of the body compared to water.

Convection Currents Result from Unequal Heating of Gases and Liquids.

Inasmuch as gases expand when they are heated, they become less dense and are, therefore, buoyed up and replaced by denser cold gases, which rise, in turn, as they are heated. Similar convection currents are produced in liquids. Very often these convection currents become visible, because liquids and solids of different densities differ also in their index of refraction. The index of refraction, as we shall learn

in a later section, is a measure of the refraction or bending that light undergoes when it passes from one medium into another. The presence of currents of warm air may thus become evident due to refraction effects of the heated air rising above a hot pavement.

The draft in a lamp chimney, stove, furnace, fireplace, or factory chimney is the upward push of a convection current. Hot-water heaters and some hot-air heating systems depend upon this principle of convection. The winds, which are so important in bringing about weather changes, are merely large-scale convection currents produced by the unequal heating of the earth by the sun. Variations in insulation and absorption due to the differences in the specific heats and heat conductivities of different kinds of materials also cause local air currents.

STUDY QUESTIONS

1. State Archimedes' principle, and show how it is applied in the use of hydrometers.
2. What is surface tension? How may it be measured?
3. State Pascal's principle, and apply it to the action of the hydraulic press.
4. How is viscosity measured? Why are motorists advised to use oil of lower viscosity in cold weather?
5. What is the principle of the storage-battery hydrometer?
6. What is the object of streamlining?
7. Why is streamlining more important for boats and airships than it is for automobiles?
8. Why is ink paper sized?
9. Describe a convenient way to measure the density of liquids.
10. For each of the applications in the summary, point out the principle upon which it is based.
11. What is meant by pressure?
12. Name two devices that depend upon the transmission of pressure by fluids.
13. Why does a cork float on water?
14. What enables an airship (such as a blimp or balloon) to rise?
15. Why do bubbles rising in boiling water increase in size as they rise?
16. Why is it easier to swim in salt water than in fresh water?
17. How could you determine the weight of a boat wthout scales?
18. How would the draft of a boat (depth to which the boat sinks in water) change on leaving a fresh-water harbor to go out to sea?

UNIT IV

SECTION 3

THE PHYSICAL PROPERTIES OF SOLIDS LIKEWISE HAVE MANY APPLICATIONS

Introduction.

In Section 2 of this Unit the fact was mentioned that certain materials such as paraffin or glass are not crystalline solids but rather highly viscous liquids or liquid solutions (sometimes called solid solutions). *B. J. Luyet* and *P. M. Gehenio* have recently advocated the addition of another state to the classification of matter, namely, the vitreous state.

Crystalline solids are produced by the relatively slow cooling of liquids; vitreous solids are produced by cooling which is too rapid to permit crystals to form.

True Solids Are Crystalline in Structure.

A true solid like ice is crystalline in nature. When heated to its melting-point, its temperature remains constant until all of the solid is melted, and a definite amount of heat is always used to melt a given weight of solid. This heat required to melt a solid is absorbed in breaking down the crystalline structure; at the melting-point the whole structure collapses.

In everyday usage the term *solid* refers to all types of materials that are sufficiently rigid to retain their shape in spite of gravity at ordinary temperatures; this includes not only the crystalline solids but also vitreous solids. Amorphous (Greek: formless) solids do not seem to come under either of the above types. Examples of such solids are the dark deposits found on the inside of incandescent light bulbs, bulbs of motion-picture projectors, and vacuum tubes; this metallic deposit is formed from the vapor of the metal which is formed when the filament is heated in such a way that no regular crystalline structure is produced. Such solids as lampblack are practically amorphous, but the majority of finely divided solids consist of very small crystals.

No System of Classification Is Adequate.

The majority of substances can be classified definitely as gases, liquids, or solids, but there are a few substances that show intermediate properties; thus vitreous liquids show by X-ray analysis that there are at least temporary crystalline structures present. Several hundred liquids which show crystalline properties are known.

Solids Have Definite Specific Heats.

The specific heat of a substance is the ratio of the amount of heat required to raise the temperature of one gram of the substance one degree centigrade to the amount similarly required for water.

A CALORIE *is the amount of heat required to raise the temperature of one gram of water from 15° to 16° C.*

TABLE OF SPECIFIC HEATS

Water	1.00	Sand	0.19
Pine wood	0.65	Iron	0.113
Alcohol	0.60	Copper	0.094
Ice	0.50	Zinc	0.093
Aluminum	0.22	Mercury	0.033

The unusually high specific heat of water has a number of important applications. In a following section we shall see how the temperature of land areas near large bodies of water is kept equable by the breezes blowing from the water to the land areas. The temperature of large bodies of water changes very little during a hot day because of the high specific heat of water. On the other hand, large bodies of water do not cool very much at night for the same reason. Inasmuch as the specific heat of land areas is much less than that of water, they are more quickly heated and cooled than large bodies of water.

Hot-water heating systems are possible because of the large amount of heat that is carried by the water and given off as the water slightly cools. The hot-water bottle is an application of the high specific heat of water. The same weight of iron would yield less than one-ninth as much heat for an equivalent temperature drop.

The Heat of Fusion of Water Is Unusually High.

When liquids solidify, heat is set free, and when solids melt, exactly equivalent amounts of heat are used up for equivalent amounts of the same substances. *The amount of heat in calories required to melt one gram of a true solid is called its heat of fusion.* The freezing of water into ice liberates so much heat that winters are moderated and the advent of spring is delayed in the neighborhood of large bodies of water because of the heat absorbed by the ice as it melts.

HEAT OF FUSION

	Calories per Gram
Sodium chloride	124
Ice	79.8
Aluminum	76.8
Copper	43
Tin	14
Lead	5.4

Le Chatelier's Law Is the Fundamental Law of Equilibria.

When a mixture of ice and water is heated, the ice melts; and the water freezes when the mixture is cooled. Both processes successfully resist a change in temperature until either the ice or water is used up. This is an illustration of a general principle formulated by *Le Chatelier*, which in simple language merely states that *when a system that is in equilibrium is subjected to a stress, the equilibrium is disturbed and a change takes place in the direction that tends to relieve the stress until the system once more reaches a state of equilibrium.* An equilibrium can be subjected to a stress by altering the temperature or pressure of the system or the concentration of one or more of the substances contained in it.

The application of this principle to physical equilibria may be illustrated as follows:

1. When a liquid in equilibrium with its vapor has heat added, part of the liquid evaporates, inasmuch as vaporization absorbs part of the added heat. If heat is removed from the system, part of the vapor condenses; and the heat thus evolved tends to compensate for the heat removed.

2. When a solid is in equilibrium with its liquid, the temperature of the system cannot be permanently altered without completely removing either the solid or the liquid. Thus ice and water will remain together without an increase in the amount of either phase as long as no heat is gained nor lost by the system. Ice will remain in water in a good thermos bottle for some time because little heat is allowed to enter the system. The temperature of a mixture of ice and water is 0° C., and it cannot be changed by either adding heat to, or removing it from, the mixture; when heat is applied, a portion of the ice melts and thus absorbs the heat; when heat is removed, a portion of the water freezes and thus evolves heat.

A tub of water may be placed in a basement to prevent the freezing of nearby vegetables. The principle of this procedure is that the heat liberated as the water is first cooled and is then frozen will help to prevent the freezing of the vegetables, which should be protected in part by being covered with cloth or earth.

3. When a snowball is squeezed, it is compacted into ice because some of the snow melts as pressure is applied, thus relieving the pressure because of the smaller volume occupied by liquid water than is occupied by the solid water or snow. When the pressure is released, the reverse process takes place; the water freezes and binds the snow together.

Liquid films are produced on ice by the pressure produced against the ice by the weight of the skater. These films offer less resistance than solid ice offers and thus enable the skater to glide over the ice very readily. The glazed tracks left on snow by a sleigh are due to a similar melting from pressure and refreezing after removal of the pressure. "Regelation" is the term applied to the melting of ice under pressure and the subsequent freezing upon release of the pressure. Glaciers are able to "flow" around obstructions by this process.

Substances like sulfur which increase in volume when melted cannot be melted by pressure.

This principle of Le Chatelier is one of the most far-reaching generalizations in the whole field of Science. Applications of it will be noted later in systems of chemical and physiological equilibria.

Heat of Fusion Is an Important Factor in Refrigeration.

The ice refrigerator illustrates an application of the high heat of fusion of ice. The heat in the refrigerator is removed by the melting of the ice. Some people wrap ice in burlap or newspapers to make it last longer, not realizing that it is the melting of the ice that keeps the refrigerator cool. Such a practice is dangerous because the temperature of the refrigerator is not kept sufficiently low to prevent the multiplication of bacteria and the false sense of security causes the owner to be less careful about cooking the foods before use than he would otherwise be.

"Dry ice" is the common name for solid carbon dioxide. In recent years dry ice has replaced water ice for many purposes because of the following advantageous properties which it possesses:

1. Solid carbon dioxide does not melt but changes directly into a gas. *This change from a solid state to a gaseous state without passing through a liquid state is called sublimation.* The rotting of wood in refrigerator cars and other places where water comes into contact with wood is thus eliminated when "dry ice" replaces water ice. The fact that no liquid is formed when "dry ice" melts is applied in packing small home containers of ice cream.

2. The gas formed when dry ice sublimes prevents bad odors in refrigerating cars and actually acts as a preservative by killing bacteria.

3. Salt is unnecessary for obtaining freezing temperatures with dry ice, thus eliminating the salt water dripping from railroad refrigeration cars which has produced considerable corrosion of the rails.

In the preparation of dry ice, purified carbon dioxide is liquefied by means of pressure. The liquid carbon dioxide is then allowed to evaporate so rapidly that a portion of the liquid is solidified as a result of the decrease in temperature caused by the absorption of heat in this process.

Solids Change in Volume When Heated.

We have already seen that a change in volume is always brought about when a gas, liquid, or solid is heated. The majority of solids increase in volume when heated, but in a few cases the solid state occupies a greater volume than the liquid state of a substance; this is one of the unusual properties of water. When water is cooled, it contracts until it reaches about 4° C. Below this temperature it expands upon cooling. The density of ice compared with water is 0.917. This means that ice is nearly one-tenth lighter than water; only about one tenth of an iceberg floats above the surface of the water.

In some respects it is unfortunate that water expands upon freezing because it causes our water pipes and automobile radiators to burst in winter. The expansive force exerted by the freezing of water is so great that few containers are able to withstand it.

On the other hand, the principle of the expansion of water on freezing has many valuable applications in nature. It has already been pointed out that surface rocks are split apart as the moisture in them is frozen in the winter. If ice were more dense than water, it would sink in the ponds and rivers as fast as it was formed in the winter; such bodies of water would freeze solid and most of their animal life would be destroyed. The oceans, lakes, and rivers would all freeze from the bottom up, and summer melting would be confined to a little slush on top.

The fact that the maximum density of water occurs at about 4° C. also enters into this problem. When water reaches the temperature of about 4° C. it begins to expand and therefore remains at the surface of the body of water. The temperature of deep bodies of water does not change much because both warm water and also water cooled below 4° C. stay at the top.

Cast iron, antimony, and its alloy *type-metal* (82 per cent lead, 15 per cent antimony, 3 per cent tin) are among the few substances that expand as they solidify. Coins made from copper, gold, silver, or nickel must be stamped on a metal disk with a heavy die rather than be cast because these metals contract as they solidify.

Allowances must be made for expansion and contraction in steam pipes and water pipes in buildings, in long pipe lines, in the construction of bridges, paving, and railroad tracks. Expansion in pipes is permitted by the use of tight sleeves, within which the pipes can work back and forth. Pipe lines use large loops, whose change in curvature will take care of expansion and contraction.

Rivets in steel girders and sheets are put in place while hot, partly because they are softer and thus easier to work at high temperatures, but also because they contract on cooling to form very tight joints. Cracks are left between sections in concrete paving; these cracks are generally filled with tar. On a very hot day the tar may sometimes be seen to bulge up at the cracks due to the expansion of the concrete.

Bimetallic-strip thermostats, widely used in temperature-regulating devices, consist of two strips of metal with different coefficients of expansion, such as brass and steel, fastened together so that the strip is bent when it is heated. Some thermometers built into ovens work on this principle.

Thermostats of certain types utilize bimetallic strips whose motion closes electric contacts or air-pressure lines, which thus regulate the heat supply or the electricity for house-heating systems, hot-water heaters, refrigerators, and electric irons.

The coefficients of linear expansion of a few common substances are shown in the following table:

Material	Ratio of Increase in Length to Length at 0° C., per Degree C.
Aluminum	0.0000255
Concrete	0.0000168 (varies with composition)
Copper	0.000014
Steel	0.000013 (varies with composition)
Lime glass (ordinary)	0.000009 (varies with composition)
Platinum	0.000009
Borosilicate glass	0.000003 (varies with composition)

Ordinary glass has to be annealed after it has been heated to a high temperature. Annealing is accomplished by cooling the glass slowly so that one portion will not cool more rapidly than another, thus avoiding strains in the glass which would result in the glass breaking too easily.

Borosilicate glass has a much lower coefficient of expansion than ordinary glass and may therefore be heated to high temperatures and be cooled quickly without fracture. For that reason it has been used in making oven-ware and laboratory apparatus. Utensils now made of specially treated low-expansion glasses may be used for cooking foods over a free flame.

Platinum has been used when it was necessary to fuse a metal into lime glass because it has the same coefficient of expansion as this glass. Metals of a different coefficient of expansion would cause cracks to form around the seal when it was cooled. Satisfactory cheap alloys such as *kovar*, which consists of a mixture of iron, nickel, cobalt, and manganese, and "Dumet" wire, consisting of a copper-clad steel wire, are now used to replace platinum in the manufacture of electric-light bulbs and other products in which metal wires must be sealed in glass.

STUDY QUESTIONS

1. How does a true solid differ from a vitreous solid?
2. Give five examples of true solids and of vitreous solids.
3. Mention two respects in which water shows unusual properties.
4. State Le Chatelier's principle and illustrate it with several examples.
5. Explain the effect of adding heat to, or subtracting heat from, a mixture of ice and water.
6. Mention three advantages of dry ice as a refrigerant.
7. Mention some of the consequences of the fact that water has its maximum density at 4° C.
8. Explain how the principle of the expansion of metals is used in a thermostat.
9. Why is borosilicate glass better than lime glass for cooking-utensils?
10. Explain how the formation of ice moderates winters.
11. Give the principle back of each of the applications listed in the summary.

UNIT IV

SECTION 4

THE ABSORPTION OR EVOLUTION OF HEAT IN PHYSICAL PROCESSES IS APPLIED IN REFRIGERATION AND HEATING-SYSTEMS

Introduction.

Any change in the properties of matter is called a *process*. A change in chemical properties is a chemical process, while a change in physical properties is a physical process. All processes involve a transformation or redistribution of energy; but physical processes do not bring about a change in composition, whereas chemical processes do.

Vaporization Absorbs Heat.

The pressure exerted by a vapor when it is in equilibrium with the liquid is called the *vapor pressure.*

The boiling-point of a liquid depends on its vapor pressure at a given atmospheric pressure. Thus a gasoline fraction which boils at 50° C. is said to be more volatile (*i.e.*, to have a higher vapor pressure at a given temperature) than another sample which boils at 60° C. Ether and acetone vaporize very readily, while mercury and glycerine, which boil at much higher temperatures, have low vapor pressures at room temperatures. *The boiling-point of a liquid is that temperature at which its vapor pressure becomes equal to the external pressure.*

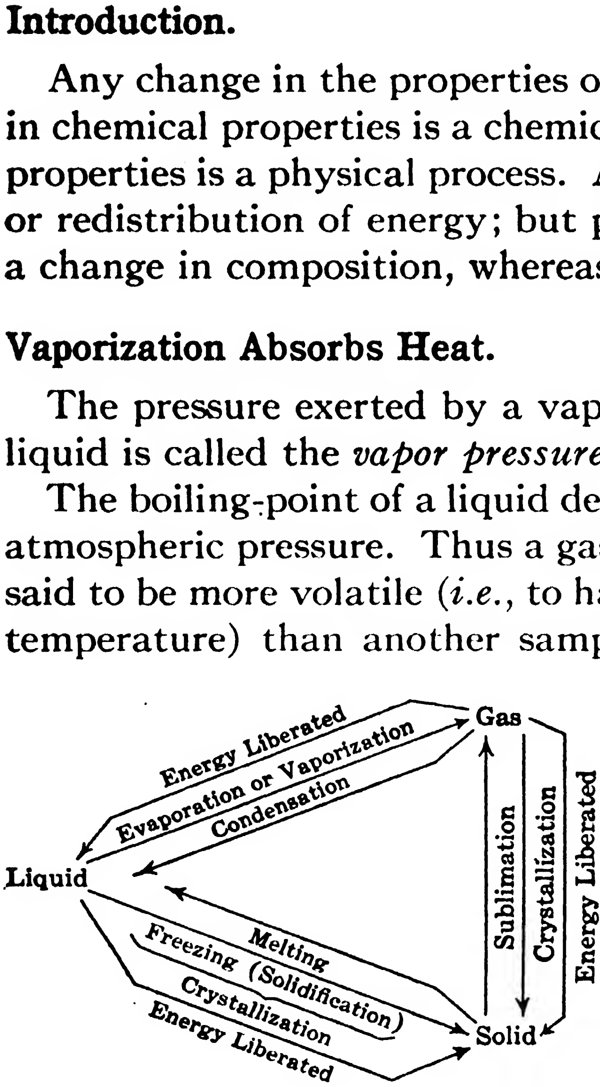


FIG. 70. The chief physical processes.

At sea level water boils at 100° C., but at higher altitudes it boils at a lower temperature because the atmospheric pressure is less than it is at sea level. At Colorado Springs, which is about six thousand feet above sea level, water boils at 90° C. On the other hand, the boiling-point of water in pressure cookers and autoclaves is higher than usual because, being sealed, the vapors produce higher than atmospheric pressures; in fact, the boiling-point is

never reached unless the pressure is sufficient to open the safety valves. If the pressure above a liquid is increased sufficiently, no temperature will be high enough to cause it to boil. The highest temperature at

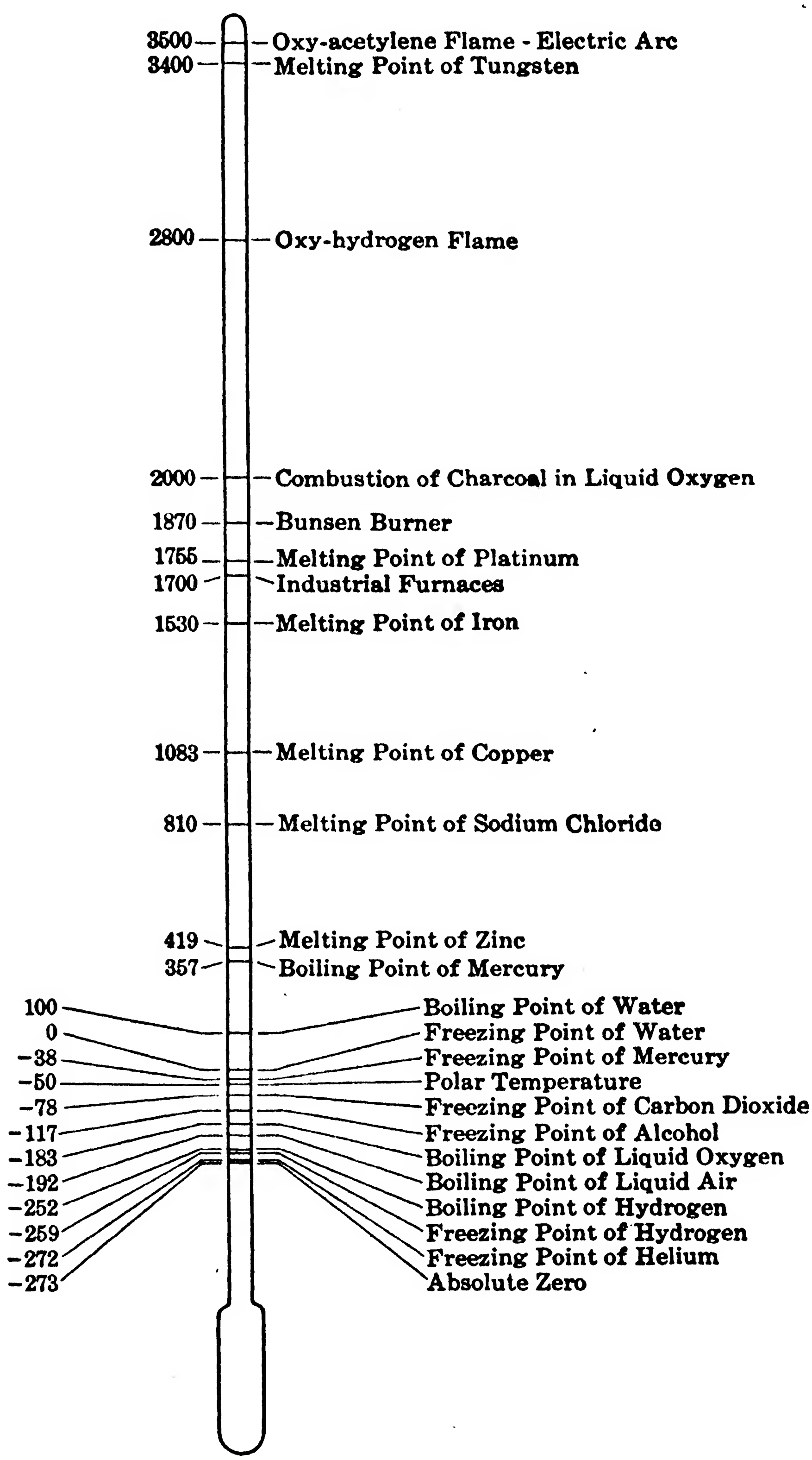


FIG. 71. Some important high and low temperatures.

which a liquid will boil is known as its *critical temperature*. Above this temperature the liquid and gaseous states become indistinguishable.

Certain gases, such as carbon dioxide, sulfur dioxide, and ammonia, may be liquefied at ordinary temperatures; but, for a long time, air,

nitrogen, hydrogen, oxygen, and a few other gases resisted all attempts at liquefaction by increase of pressure. Finally it was discovered that the critical temperatures of these gases were lower than ordinary temperatures. Then it became a simple thing to liquefy them by lowering the temperature at the same time that the pressure was increased. Figure 71 shows the boiling- and freezing-points of some common materials. In order to liquefy any gas or vapor, one need only cool it below the boiling-point at standard pressure. Thus steam may be liquefied at 100° C. Likewise, if one should cool air to a temperature of − 190° C., it would liquefy. This is a very difficult process, however, and it has been found that air will liquefy at much higher temperatures by raising the boiling-point with a great increase in pressure. In order to liquefy air, therefore, it is only necessary to compress it and allow a portion of it to expand. This expansion process cools the rest of the air which has been compressed below the critical temperature. The cooling effect is an example of the general principle that a gas absorbs heat when it expands.

Liquid Air Is Extremely Interesting.

The experiments which can be performed with liquid air are extremely interesting because they enable one to observe the properties of various kinds of matter at very low temperatures.

The word "zero" when referring to the Fahrenheit temperature scale brings to the minds of most people visions of a midwinter cold spell. A temperature of 20° or 30° below zero Fahrenheit reminds us of Siberian or Canadian winters, while 50° below zero calls to mind the worst features of Polar expeditions. Liquid air, however, boils at 377° below zero; it will boil merrily on a cake of ice.

A teakettle containing liquid air when heated over a flame will form a white deposit of solid carbon dioxide and water ice, which results from cooling the products of the combustion of gas.

Liquid air must be kept in open containers protected by a vacuum jacket; a thermos bottle meets these conditions. In even the best of these containers sufficient heat is absorbed to keep the liquid air evaporating. The pressure produced by the evaporation of liquid air in a closed container would eventually blow it to pieces. This is well demonstrated by placing a cork in a heavy glass tube containing liquid air.

Toy steam engines will run furiously when liquid air is placed in their boilers.

Toy rubber balloons may be inflated by attaching them to a tube containing liquid air. This illustrates the fact that liquid air expands eight hundredfold upon vaporization.

If liquid air remains in contact with the skin very long, it freezes it and leaves a bad burn similar to that produced with a red-hot iron.

Flowers become so brittle in liquid air that they can be broken like thin glass. A rubber tube can be broken into pieces with a hammer, while a rubber ball cooled in liquid air will break into many pieces when thrown against a wall.

Mercury may be frozen to a solid in liquid air, as may many other liquids such as kerosene, alcohol, and glycerine.

Natural gas is readily liquefied by running it into a flask cooled by liquid air.

Liquid air is widely used in scientific work to obtain low temperatures.

The Heat of Vaporization Has Important Applications.

When water is vaporized, heat must be applied. As water is heated, part of the heat is used up in raising the temperature of the water; but when the boiling-point has been reached, all of the heat is used in vaporizing the water, the temperature of the water remaining constant. Highly volatile liquids, like ether, will quickly vaporize when poured on the hand, which will itself be cooled by the process because the heat required is taken from the hand. Each different kind of liquid has its own *heat of vaporization*, which is defined as *the amount of heat (in calories) required to vaporize one gram of a liquid at its boiling-point.*

Heat of Vaporization

Water	538
Ammonia	294
Ethyl alcohol	205
Mercury	68
Chloroform	58

Refrigeration units are cooled by the vaporization of a liquid in the cooling coil. Liquids of high heat of vaporization are naturally most efficient for refrigeration purposes and for transmitting heat.

The heat of vaporization of water is higher than that of any other known liquid, nearly six times that of liquid sulfur dioxide and nearly ten times that of liquid carbon dioxide.

This high heat of vaporization of water is of great importance in understanding many of the weather changes which will be described in later sections of this Unit. It results in the maximum amount of heat with the return to the boiler of a minimum weight of condensed material in steam-heating systems, because it gives off more heat than an equal weight of any other liquid would when it is condensed. A mixture of diphenyl and diphenyl oxide does not exert such dangerously high

pressures in boilers as does water at the high temperatures necessary for high efficiency in power generation, and thus replaces the boiler water in some power plants.

A liquid suitable for use in refrigeration must be readily liquefied by pressure at ordinary temperatures; *i.e.*, its critical temperature must be above room temperature. Water should meet the requirements of a good refrigeration liquid because it is easily condensed and has a high heat of vaporization, but inasmuch as its boiling-point is 80° C. above ordinary room temperatures, it does not vaporize rapidly enough at ordinary pressures to be effective. Air is often cooled by the vaporization of water, however. A simple house air-cooler, shown in the

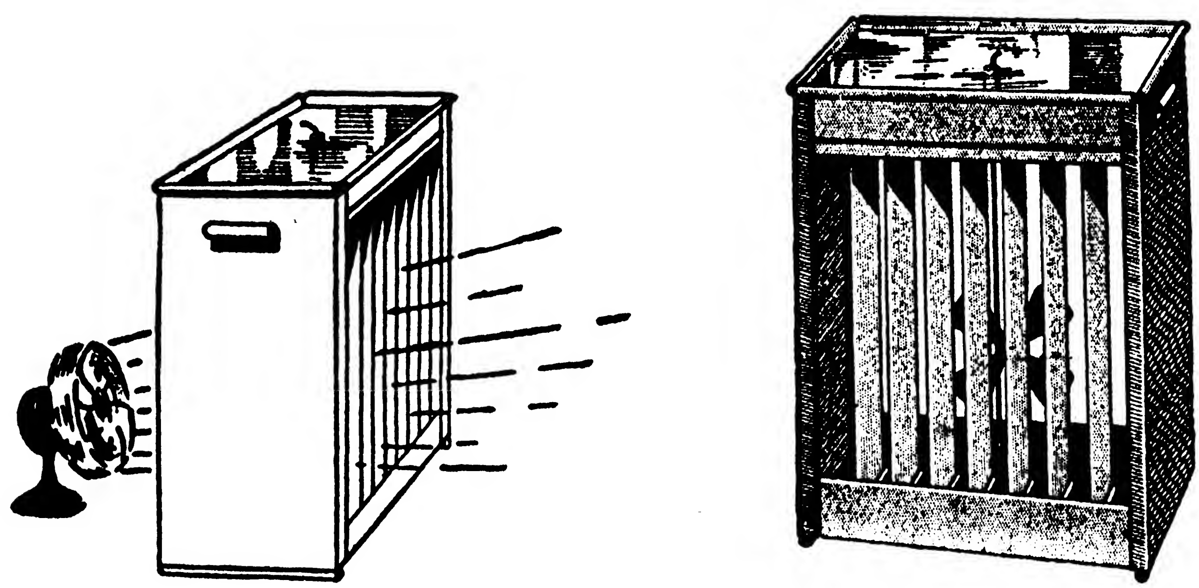


FIG. 72. A very simple type of air-conditioning unit. The fan blows air over the long wet wicks.

illustration, depends upon increasing the cooling by evaporation by directing a current of air against a wet cloth by a fan.

Desert water bags are kept cool by the evaporation of the moisture which seeps through the canvas bags. Refrigerators covered with moistened cloth are sometimes used for camping trips.

Nearly everyone has experienced the cooling of the body when standing in a wind when clothed with wet garments.

Inasmuch as the liquid in a refrigeration system must be condensed as rapidly as it vaporizes, some provision must be made for this process. In the majority of refrigeration systems, small or large, the vapors are condensed by power-driven compressors.

The gas-operated refrigerator originated as an invention of two Swedish students, *Carl Munters* and *Baltzar van Platen*, who made their brilliant discovery while still undergraduates at the Royal Institute of Technology at Stockholm. The process represents an ingenious

application of the physical changes which we have studied, but it is too involved to permit a thorough discussion in the text. In general, it depends upon the driving off of ammonia from its water solution by heat, condensing the ammonia by cool water or indirectly by relatively cool air, cooling the refrigeration coil by expansion of the liquid ammonia, and absorbing the ammonia in water again. The absorption of the ammonia in water corresponds to the compressor in the mechanical refrigeration unit.

Inasmuch as heat is used up in vaporization, the reverse process of condensation evolves heat, which must be removed before the compressed gas can be liquefied. In the gas refrigerator the vapor is cooled by water or by air as in automobile engines. All automobile engines are cooled by air. Air-cooled airplane engines are so constructed that their cylinders are cooled with a rapid stream of air produced by the motion of the airplane. Most automobiles take advantage of the specific heat of water, which permits it to transmit the heat to a radiator specially designed to give efficient cooling when the air is kept in circulation through it by a fan. The heat is thus transmitted from the water to the metal which warms the air in contact with it. The fan moves the heated air away from the radiator and thus maintains a supply of relatively cool air.

In large refrigeration plants such as ice plants, the compressed gases are cooled by water, which is cooled, in turn, by vaporization in evaporation towers. Thus the heat used up by the vaporization of the water in the evaporation towers is indirectly responsible for the freezing of the ice in the ice plant.

One of the objections to electric refrigerators is that moisture is removed from uncovered foods placed in the refrigerator. One method of preventing this dehydration of foods is to increase the cooling area and keep it about 10° F. above the freezing-point of water. Microorganisms are more likely to multiply at this temperature than at the lower temperatures usually required to preserve foods in refrigerators, but this problem has been solved by the use of a germ-killing lamp to destroy the bacteria in the air and in foods exposed to the ultraviolet radiations given off.

STUDY QUESTIONS

1. Why does liquid air boil on a piece of ice?
2. Give some examples of the change in properties of matter at the temperature of liquid air.
3. How is air liquefied?
4. Why can air not be liquefied by compression alone?

5. How would you change water vapor into liquid water?
6. Define the following processes, and state whether the process liberates or absorbs heat: vaporization, melting, sublimation, distillation, freezing condensation.
7. What is the principle of mechanical refrigerators?
8. What is the principle of the gas refrigerator?
9. Why does water boil at a lower temperature on a mountain than it does at sea level?
10. What is vapor pressure, and how may it be measured?
11. Explain the principle of pressure cookers and autoclaves.
12. Mention two applications of the high heat of vaporization of water.

3. Colloidal Dispersions. Colloidal dispersions (colloids, or colloidal solutions) are mixtures whose dispersed ingredients range in size from about 1 to 100 millimicrons in diameter. The ingredients in a colloidal dispersion cannot be seen except with the aid of an ultramicroscope, and not always then.

The physical properties of colloids differ considerably from the properties of solids, liquids, and gases because the particles are much larger than molecules. For that reason, many people consider colloidal dispersions to represent a special state of matter.

Inasmuch as the dispersed and dispersion phases may exist in the solid, liquid, or gaseous states, nine types of colloidal dispersions would seem to be possible. These nine types are listed as follows with examples illustrating the type in each case, although the dispersed phase in some of the mixtures mentioned is usually larger than colloidal in size.

State of Dispersion Medium	State of Dispersed Phase	Example
Solid	Solid	Chinaware or porcelain, gold in ruby glass
Solid	Liquid	Uncombined water in rocks
Solid	Gas	Biscuits, cake, or marshmallows (The dispersion medium in this case is a plastic solid.)
Liquid	Solid	Chocolate drink or muddy water
Liquid	Liquid	All such mixtures are called *emulsions* Examples: milk or mayonnaise
Liquid	Gas	Foam, whipped cream
Gas	Solid	Dust, smoke
Gas	Liquid	Fog, clouds
Gas	Gas	Impossible because all particles are molecular in size

Colloids will be studied in more detail in Unit X, Section 1.

4. Solutions. Solutions are molecular dispersions; *i.e.*, the particles of both phases are molecular in size. The diameters of such particles range from 0.2 to 1 millimicron.

Solutions differ from coarse and fine dispersions in that they are *homogeneous*. In this respect they resemble substances; but they must be regarded as mixtures, nevertheless, because *their composition may be varied over rather wide limits without producing any abrupt change in their properties.*

Substances Differ Widely in Solubility.

The *dispersed portion of a solution* is called the *solute*, while the *dispersion medium* is called the *solvent.* The *solubility* of a substance

is *the ratio of the quantity of solute to the quantity of solvent in a saturated solution.*

A *saturated solution* is *one which is in equilibrium with the undissolved solute.* It represents a dynamic condition in which molecules of solute are dissolving just as rapidly as they are coming out of solution. A saturated solution of sugar in water can be prepared by stirring sugar in water until no more sugar dissolves. A quicker way to prepare it is to heat the water and stir in sugar hastily, making sure that there is an excess of undissolved sugar, and then cool to the desired temperature. Inasmuch as the amount of sugar which dissolves in water increases with a rise in temperature, a nearly saturated solution at a high temperature contains more sugar than a saturated solution at a lower temperature. Therefore, the excess sugar crystallizes out when the solution is cooled, leaving a saturated solution.

Supersaturated Solutions Are Well Known in the Home.

If the nearly saturated solution should be allowed to cool after removing the undissolved solute, the excess sugar might not crystallize out, and the solution would be said to be *supersaturated.* If a crystal of undissolved solute should be added to a supersaturated solution, the excess solute would begin to crystallize at once. A supersaturated solution may readily be prepared for demonstration by melting crystalline "photographer's hypo" and allowing it to cool. The cold supersaturated solution quickly crystallizes upon dropping in a small crystal of "hypo." The solution expands as it crystallizes and often breaks beakers or other containers in which the crystallization is allowed to complete itself.

Supersaturated solutions are frequently met with in the home. Honey, for example, is a supersaturated solution. Sometimes crystals of sugar form in the honey. Addition of sugar would bring this about, but the usual cause of the formation of sugar crystals in honey is undue cooling. If a supersaturated solution is cooled sufficiently, the supersaturation becomes so great that crystals form even without seeding with sugar or some other small particles around which sugar might form. Honey is likely to "sugar" in the winter, and it is obvious that it should not be kept in a refrigerator.

In making some types of candy, it is desirable to obtain a supersaturated solution. Inasmuch as glucose crystallizes less readily than cane sugar, glucose is used in making such candies; or some acid substance like vinegar, lemon juice, or cream of tartar is added to cane sugar to cause it to change to glucose and fructose. Such candies are stirred as little as possible. Taffy and butterscotch candy are typical

supersaturated solutions. Fudge is crystalline, and it is stirred rapidly while cooling to insure crystallization. Stirring is frequently all that is necessary to cause the excess solute in a supersaturated solution to separate out.

Jellies are supersaturated solutions, and sometimes the excess sugar crystallizes out in beautiful large cubes called "rock candy." Rock candy can also be made by hanging a string in a supersaturated solution of sugar in water, the excess sugar crystallizing on the string.

Gases and Liquids Show Great Variations in Solubility.

Gases are completely **miscible** with other gases. This means that they are mutually soluble in each other in all proportions. Thus the atmosphere is a mixture of the gases, nitrogen, oxygen, carbon dioxide, water vapor, and a few rare gases that are completely miscible in each other. Some liquid pairs, such as alcohol and water, or kerosene and gasoline, are completely miscible with each other, but many liquids are only partially so; gasoline and water are slightly miscible in each other.

A **concentrated** solution is one that contains a relatively large amount of solute in a given amount of solvent, whereas a **dilute** solution contains a relatively small amount of solute in a given amount of solvent.

The Amount of Gas Which Will Dissolve in a Liquid Depends upon the Temperature and Pressure.

The individual (specific) properties of different gases make their solubilities in a given liquid solvent different.

Relative Solubilities of Common Gases in Water. Hydrogen, nitrogen, and oxygen are slightly soluble, 2–4 volumes to 100 volumes of water.

Carbon dioxide and chlorine are fairly soluble, several hundred volumes to 100 volumes of water.

Sulfur dioxide, ammonia, hydrogen chloride are very soluble, several thousand volumes to 100 volumes of water.

In the case of very soluble gases, there is probably a chemical union of the solute particles with the water molecules.

Slightly or fairly soluble gases follow the gas laws when they are dissolved in liquid solvents; it has been observed that *an increase in pressure will increase the weight of gas dissolved in a given volume of liquid*. This is a statement of *Henry's Law*.

The increased solubility of carbon dioxide in water with increased pressure is used in preparing carbonated drinks. When the cap of a soda-water bottle is removed, the liquid effervesces because the pres-

sure has been released, thus allowing the extra gas to escape from solution.

In making alcoholic liquors by fermentation, in which the liquor is bottled before fermentation is complete, the amount of carbon dioxide formed by the fermentation after bottling frequently becomes so great that all of the liquor shoots out of the bottle along with the gas when the cap is removed. This effect would be decreased by cooling the bottle before opening it, because gases become more soluble at lower temperatures. The solubility of gases decreases as the temperature is raised, until, when the boiling-point of the solvent is reached, most gases become completely insoluble.

All of the gases dissolved in water could thus be removed by boiling the water, unless they form compounds with the water or constant-boiling solutions. It is the gases dissolved in ordinary water that give it the palatable properties to which we are accustomed and which we therefore prefer. Freshly boiled water has an objectionable flat taste which is removed by simply pouring it from one vessel to another through the air a few times to dissolve some air.

When water is heated, bubbles of gas are observed to form on the side of the heating vessel long before the boiling-point is reached. These bubbles form, of course, because the solubility of the gas is reduced as the temperature is raised.

Although the solubility of oxygen in water is very small, it is very important. Most fish have gills with which to remove the dissolved oxygen from the water. The water of small aquariums should be changed or agitated regularly in order to dissolve more oxygen in the water to replace that taken out by the fish.

The Properties of Liquid Solvents Are Changed to the Same Extent by Equivalent Amounts of Liquid or Solid Solutes.

1. The Vapor Pressure Is Lowered. Equivalent amounts of solutes (that is, weights that contain the same number of molecules or other particles of solute) lower the vapor pressure of solvents to the same degree. Thus a little glycerine or sugar might be added to a skin lotion to keep the skin from getting dry because these substances would lower the tendency of the moisture of the perspiration to evaporate and would thus tend to retain the moisture of the skin.

Some substances, such as calcium chloride, sodium or potassium hydroxide, and sulfuric acid, are so soluble in water that they lower the vapor pressure of the film of moisture that condenses on their surface to the extent that it is below that of the water vapor in the air. In such cases moisture continues to collect on the surface of such sub-

stances until they dissolve in a little pool of water thus taken from the air. Such a process is called *deliquescence.*

Calcium chloride has been used widely to lay the dust and keep roads in shape. The calcium chloride is spread over the road and keeps the surface moist by the water which it absorbs from the air.

There are other substances, containing water of crystallization, in which the vapor pressure of the water present is greater than that of the water vapor in the air. Such crystalline substances will lose water, especially in a dry atmosphere, and fall apart as a powder. Washing soda does this, as the labels on small commercial packages indicate. Such substances are said to *effloresce,* and the process is called *efflorescence.*

2. The Boiling-point Is Raised. Inasmuch as the vapor pressure of solvents is decreased when solutes are dissolved in them, it would follow that a higher temperature would have to be attained in order to increase the vapor pressure to the point where it is equal to the opposing pressure of the atmosphere. The boiling-point of a given weight of any liquid solvent is raised to the same extent by equivalent weights of all nonvolatile solutes.

Inasmuch as water boils at lower temperatures at high altitudes than at sea level, it takes longer to cook foods by boiling them in water at higher altitudes. This can be remedied somewhat by adding salt to the water and thus raising the boiling-point. Practically everyone has learned by painful experience that the sugar and other solutes added to water in making cocoa cause it to boil at higher temperatures than water itself would. Boiling cocoa is hotter than boiling water. It is a common observation that a boiling solution of sugar in water, such as we prepare in making candy, will cause a much more severe burn than boiling water alone.

3. The Freezing-point Is Lowered. Solutes lower the freezing-point of a given weight of a given solvent the same amount for equimolecular weights of substances provided that they do not dissociate when dissolved. Many kinds of substances are used to lower the freezing-point of water in order to keep it from freezing in automobile radiators, meters, and other devices that would be broken by the expansion resulting from the freezing of the water.

The molecular weights of a few such "antifreeze" substances are given as follows:

Cane sugar	342 g.
Ethyl alcohol	46 g.
Methyl alcohol	32 g.
Glycerine	92 g.
Ethylene glycol	62 g.

Other things being equal, the substance having the smallest molecular weight would be selected for use as an antifreeze substance. Other important considerations are cost and the volatility of the antifreeze substance. Inasmuch as ethyl and methyl alcohols boil below the temperature of water, they are gradually lost when the automobile engine gets hot and would have to be renewed two or three times during a winter. The other substances would not be lost in this way because they are less volatile than water, and it might be more economical to use one filling of such a substance even at a higher price than several fillings of the cheaper, more volatile substances.

Salt is mixed with ice in making ice cream in order to lower the melting-point of the ice. This is necessary because the sugar and other solutes dissolved in the water of the ice cream lower its freezing-point below the melting-point of ice. Salt is scattered on icy walks to remove the ice because it lowers the melting-point of the ice and thus causes it to melt.

Ocean water does not freeze as readily as fresh water because of the salts dissolved in it.

Brine is used in commercial ice plants to conduct to the cooling-coils the heat from the cans of water to be frozen.

4. The Osmotic Pressure Is Produced. If a membrane, such as parchment paper or an animal bladder, is placed between two solutions of different concentrations, it will be found that solvent particles will pass through the membrane in the direction of the more concentrated solution more rapidly than the solute particles will pass through the membrane in the opposite direction. *The passage of solvent through a membrane into a solution is called* OSMOSIS; *the passage of a solute through a membrane is called* DIALYSIS. Most membranes permit both dialysis and osmosis; but if a proper membrane could be secured, osmosis alone would take place.

If osmosis were allowed to continue until the water ceased to rise in the tube, *the hydrostatic pressure thus produced would be a measure of the osmotic pressure of the solution.* It has been found that *the osmotic pressure of dilute solutions of equimolecular concentration is the same for different substances* when there is no dissociation of the solute and that it is independent of the character of the solute.

The osmotic pressure exerted by a substance in solution is equal to the gas pressure which that substance would exert if it were a gas occupying the same volume as that of the solvent, under the same conditions of temperature. The solution state is very similar to the gaseous state in that osmotic pressure is affected in the same way by temperature and volume changes as are gaseous pressures. It is impor-

tant to note that the laws dealing with the behavior of substances in solution apply only to very dilute solutions.

Osmosis is explained in a number of different ways. The sieve theory, for example, assumes that the solute particles are too large to pass through the openings in the membrane, while the solvent molecules are sufficiently small to do so. There is considerable evidence that each solute particle is joined to one or more solvent particles in solution. This fits into the sieve theory nicely and also explains why the gas laws do not apply to concentrated solutions. In such solutions so much of the solvent would thus be joined to the solute particles that there would be a much smaller volume of free solvent than there is assumed to be in making calculations involving the volume.

Osmosis is also explained as the result of the solution of one of the phases in the membrane.

If particles the size of *solvated* [1] solute particles could pass through a membrane whose openings were too small to admit the passage of the still larger colloidal particles, the solute and colloid would thus be separated. Of course, openings large enough to admit the passage of solute particles would also admit the solvent molecules, so osmosis always takes place during dialysis. Dialysis does not always take place, however, when there is osmosis.

Osmosis and dialysis have many important applications in living organisms because every living cell is surrounded by a membrane through which it makes necessary interchanges with its environment.

If oysters are placed in distilled water they swell because of osmosis, inasmuch as the solutions inside the oyster have a much higher osmotic pressure than distilled water — they have been in equilibrium with the sea water in which the oyster grew. Some unscrupulous markets have taken advantage of this idea to increase the size and weight of their oysters before selling them.

If plant cells are placed in salt water, they wilt and lose their turgor. This is due to the fact that water passes from the plant cells to the salt water. Such a process is called *plasmolysis*.

One type of remedy for intestinal stasis involves the use of saline laxatives. Such substances as sodium sulfate (Glauber's salt), magnesium sulfate (Epsom salts), magnesium citrate, and milk of magnesia flush out the intestinal tract by the water drawn from the blood as a result of the higher osmotic pressure their presence produces in the intestines.

One objection to the use of saline laxatives is that they not only remove water from the blood but that they also bring about a loss of

[1] When a solute combines with a portion of the solvent, the solute is solvated.

valuable mineral substances by selective dialysis. One method of eliminating this objection is the practice that many people have of drinking a glass or two of lukewarm normal saline solution about a half-hour before breakfast. The term "normal" here refers to the fact that the saline solution, which is about 0.9–1 per cent and contains two level teaspoons of common salt to a quart of water, is isotonic with the blood. The body receives its food by dialysis through the membranes in the intestinal tract, so that both dialysis and osmosis take place at the same time. A solution having the same osmotic pressure as the blood would be called *isosmotic* with the blood, but such a solution might still change in concentration as the result of dialysis either from it to the blood or vice versa. A solution which does not change either by osmosis or dialysis when placed on the opposite side of the membrane to that of the blood is said to be *isotonic* with the blood.

The chemical garden is an excellent illustration of osmosis. It is prepared by dropping little crystals of very soluble colored salts such as ferric chloride, nickel chloride, cobalt nitrate, manganese nitrate, uranium nitrate, copper sulfate, etc., into a 10 per cent sodium silicate solution. These salts dissolve in the film of water surrounding the crystal, and the resulting solution reacts with the sodium silicate to form membranes. Water passes by osmosis into the crystal side of the membrane and finally bursts the membrane. The solutions thus form new membranes, and the growth continues. Your instructor will undoubtedly demonstrate the chemical garden for you.

The lowering of the vapor pressure and the freezing-point, the elevation of the boiling-point, and the osmotic pressure of solutions are all due to the number of molecules present rather than to their chemical composition. It is possible, therefore, to estimate the relative number of molecules of any solute present in a given weight of solvent by measuring the above properties of the solutions in question.

It should be added here that there is a group of substances for which the above properties are abnormally high. The simplest way to explain such abnormalities is by saying that the molecules must have subdivided to form a larger number of smaller particles, each of which produced the same effect as the original molecule. Such abnormalities, characteristic of solutions of electrolytes, will be studied in a later unit.

STUDY QUESTIONS

1. Define: solvent, solute, and solution.
2. How does water behave when it is cooled from 20° C. to −10° C.?
3. Give an example of a supersaturated solution.

4. What is deliquescence? Give an application.
5. What is the effect of temperature on the solubility of a gas in a liquid?
6. What is the effect of pressure on the solubility of a gas in a liquid?
7. What is the effect of dissolved substances on the boiling-point, freezing-point, and vapor pressure of liquids?
8. What is osmosis? Describe an experiment illustrating osmosis.
9. What is the relation of osmotic pressure to the concentration of a solution?
10. Explain the use of calcium chloride on dusty roads.
11. How would you prepare a saturated solution?
12. How would you prepare a supersaturated solution?
13. Explain the use of vinegar or cream of tartar in making candy.
14. Why do red blood cells burst when they are placed in distilled water?
15. Explain the physiological effect of Epsom salts.
16. How would you prepare a normal saline solution? Is it isotonic or isosmotic with the blood?

UNIT IV

SECTION 7

CLIMATE AND WEATHER ARE PRODUCED BY PHYSICAL CHANGES

Introduction.

In general man seems to thrive best in climates in which extremes of heat and cold, dampness and dryness are avoided. A climate can be too equable; a climate of unvarying temperature, whether it be hot, cold, or ideal, is not only monotonous but depressing and enervating. Man seems to do his best work in climates where the temperature changes decidedly from season to season and from day to night.

It is the object of this Section to show that climate and weather are a matter of physical cause and effect. This study of climate and the weather is generally referred to as the science of *meteorology*.

Climate Is Controlled in Part by the Distribution of Land and Water.

Continental climates show greater temperature ranges, less frequent rainfall, and more sunshine than marine climates. Desert climates represent the extreme of continental climatic conditions, with their hot days, relatively cool nights, and low average rainfall. Large bodies of water experience relatively small or slow temperature variations because of the high specific heat of water, as has previously been explained. In the daytime a large portion of the sunlight is lost by reflection from the surfaces of bodies of water, while much of that sunlight which is absorbed is used up in the process of evaporation. The amount of sunlight that is absorbed as heat is insufficient to raise the surface temperature of the ocean even a degree in a day because of the high specific heat of water and the cooling effect of evaporation. Land areas, on the other hand, reflecting less heat than water areas and being composed of materials of relatively low specific heat, become heated or cooled rapidly. Heat is also distributed by motions within the water, whereas land is immobile.

The climate on the western shores of continents in the temperate zones is generally more equable than that on eastern shores due to the effect of the prevailing winds from off the oceans. The prevailing winds

vary because of seasonal changes and differ from place to place, but in general they blow from westerly directions in the temperate zones because of the effects of the rotation of the earth on the circulation of the atmosphere.

Winds blowing toward the equator from higher latitudes are deflected westward; these prevailing northeasterly and southeasterly winds of the tropical regions are called the trade winds.

There are belts of comparative calm at about 30° latitude north and south, between the trade winds and the prevailing westerlies. Here the atmosphere forms high-pressure belts, particularly over the

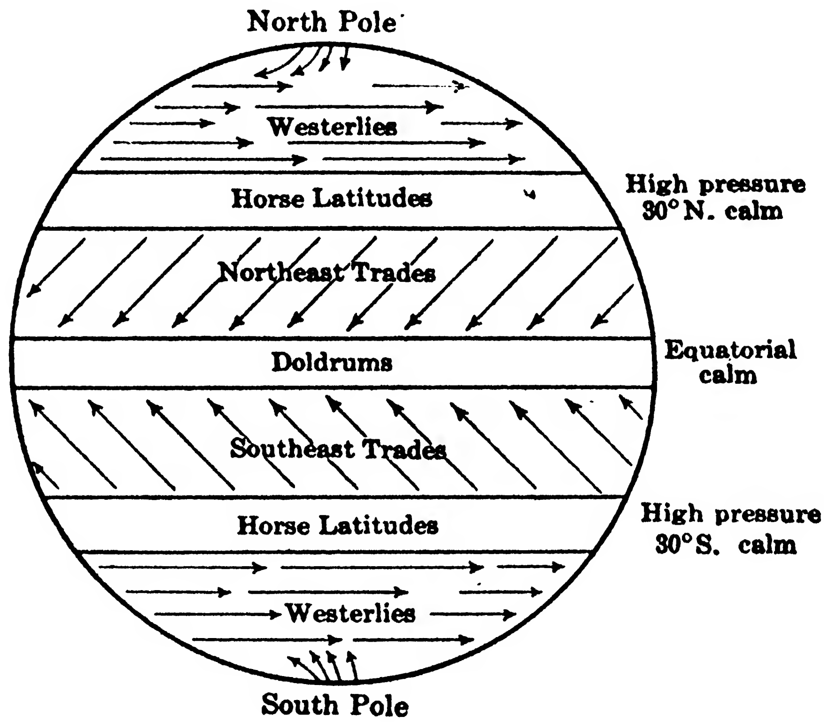


FIG. 75. The most important prevailing winds on the earth.

oceans. These latitudes are called *horse latitudes* because sailing vessels carrying horses from New England to the West Indies were obliged to throw a part of their cargo overboard when water became scarce because of slow progress due to the lack of winds. In these latitudes one would expect to find the chief desert regions of the world.

The prevailing westerly winds are especially well developed in the southern hemisphere, where, free to blow with great violence, they are known as the *roaring forties*.

The area of equatorial calm called the *doldrums* shifts north and south with the seasons.

Near the poles the atmosphere is cooled and flows away from the poles.

The prevailing winds tend to move the water at the surface of the oceans by friction in the direction in which they are blowing. The waters are thus blown toward the equator by the winds from the north.

At the equator these waters move westward in the Atlantic and Pacific oceans. The westward current in the Atlantic Ocean at the equator divides, one branch flowing northward past the West Indies, through the Caribbean Sea and the Gulf of Mexico, and past Florida as the Gulf Stream. The equatorial stream in the Pacific divides near the islands of Australia, the northern branch becoming the Japan Current. It must not be thought, however, that the only cause of ocean currents is the wind. It is probable that differences in the densities of water due to differences in salt content and other factors also cause ocean currents.

These ocean currents seldom average more than three or four miles per hour, but they tend to equalize the temperature of the globe by making the waters of the equatorial zones cooler and the waters of the polar regions warmer. These ocean currents, influencing the temperature of the winds that blow over them, make the climate more equable on the portions of the continents *in line with these winds.*

The Japan Current divides on reaching the western coast of North America, the northward portion becoming the Alaska Current, and the southward portion becoming the California Current.

Arid Regions Are Found on the Leeward Side of Well-watered Mountain Ranges.

The mountains along the Pacific coast in the United States produce conditions leading to the precipitation of much of the water from the winds that sweep up and over them; and inasmuch as these mountains are transverse to the prevailing winds, the regions on the other side of the mountains receive very little rain. The Appalachians present no such effective barrier — they are not so high and are more or less parallel to the prevailing winds during much of the year.

Climates Differ with Altitude.

The temperature of the free air decreases on the average of 1° F. (though the rate of decrease varies widely from place to place and from time to time) for every three hundred feet of rise, so that the climate of the highest mountains resembles that of polar regions. The snow line represents the altitude at which snow is found most of the year. The snow line is higher with higher mountains and varies with the latitude, of course.

The Inclination of the Earth's Axis to the Plane of the Earth's Orbit about the Sun Is the Cause of the Seasons.

Figure 77 is based on observations that the axis of the earth is always inclined at an angle of 23½ degrees to the plane of the earth's

orbit. For this reason the north pole is inclined toward the sun for half of the year, and the south pole is inclined toward the sun during the other half of the year. The two extreme positions occur on June 21 and December 22.

The four seasons do not exist at the equator, and the days and nights there are of the same length. North of the equator the days become shorter from June 21 to December 22, while they become longer during the same period in the southern hemisphere. The diagram shows that the day is twenty-four hours long at the Arctic Circle on June 21, and the night is twenty-four hours long on December 22.

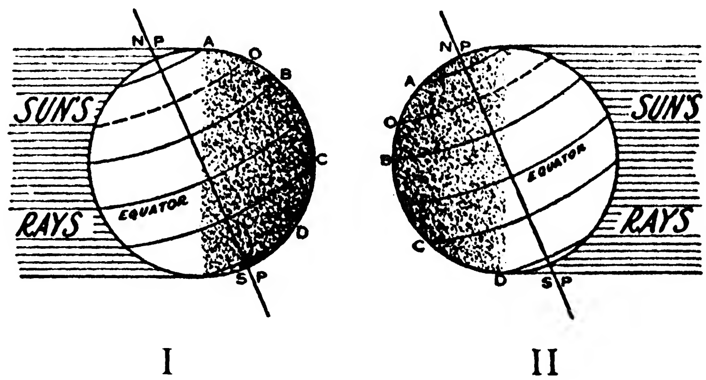


FIG. 76. I, the earth in June; II, the earth in December. (From the Yerkes Observatory, reprinted by permission of the Chicago University Press.)

The coldest period in the northern hemisphere at present is that time when the earth is closest to the sun, but every 13,000 years this condition is reversed because of precession. The distance from the earth to the sun varies from 91,500,000 miles to 94,500,000 miles, because the earth travels in an elliptical path. The seasons in the southern hemisphere are more extreme; and in the northern hemisphere it is warmer during the winter and cooler during the summer than it would otherwise be, because the earth is closest to the sun when it is winter in the north.

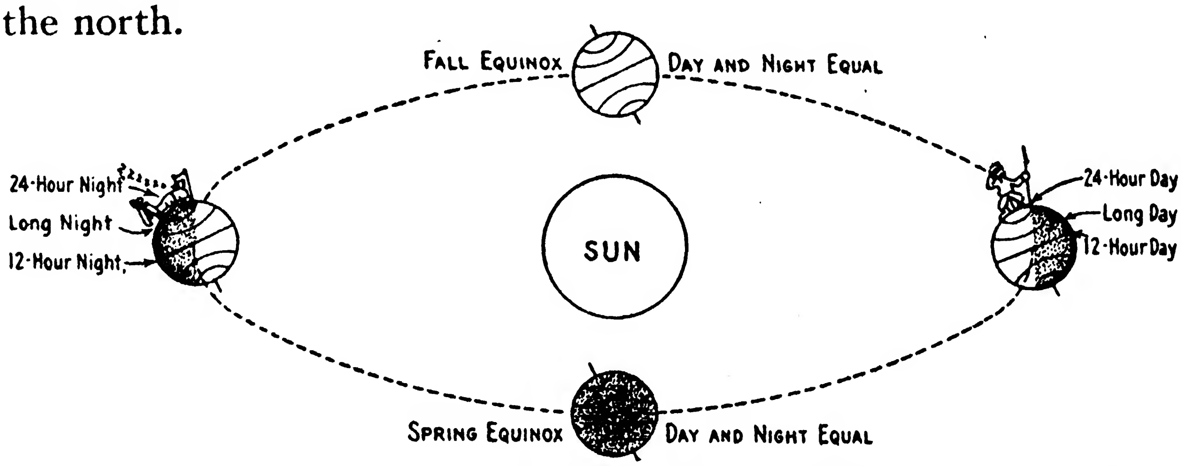


FIG. 77. The seasons; a diagram of the earth in various positions in its orbit illustrating the cause of the seasons.

The amount of heat received by the earth in the different latitudes is determined not only by the lengths of the days and nights but also by the angle at which the sun's rays strike the earth. Thus the winter is not as hot as the summer, just as the evening is not as hot as the noonday.

In the tropics there are no well-defined seasons as far as temperature is concerned; but the rainfall does vary, and wet and dry seasons are recognized. In the arctic and antarctic zones, summers are short and winters are long, whereas spring and autumn are of brief duration. Near the poles, the chief difference between the seasons is in the amount of light received; here one would refer to the light and dark seasons. In the temperate zones the four common seasons of varying temperature and length of day (*i.e.*, winter, spring, summer, and autumn) are well known. This change in the seasons is one of the major factors in producing changes in weather and will be discussed in a later paragraph.

The unequal distribution of the sun's heat between the equator and the poles is the cause of the most widespread variations in climate. The equatorial regions receive more radiant energy from the sun than do the polar regions; it is always warm at the equator and always cold at the poles.

It Takes Time to Heat the Earth's Surface.

On June 21 or 22 the sun reaches its most northerly position and turns southward again. In spite of this fact the hottest month in the United States is July. The earth loses heat by the process of radiating it to interplanetary space; and the rate of radiation is the greater the higher the temperature.

Even after the days begin to shorten, more heat continues to be received from the sun than is lost by radiation, because the earth has not yet warmed up to the temperature where the rate of loss is as great as the rate of gain; but as the temperature increases, while the days keep on shortening, the rate of loss finally becomes as large as the gain, and the temperature ceases to increase.

Because of the continual redistribution of heat by winds, ocean currents, etc. and because of the different thermal properties of different kinds of surfaces, the duration of the lag of highest and lowest temperatures behind the longest and shortest days is widely different at different places on the earth. In southern Arizona and New Mexico the highest normal daily temperatures come only 10 days after the longest day. Around the Gulf of Mexico and the Atlantic coast the lag is about 40 days. In the central states the lag is about 30 days, and in San Francisco it is 100 days, although at Sacramento, less than 100 miles inland, the lag is 37 days.

Weather Is Caused by Atmospheric Circulation.

"Weather" differs from "climate" in that weather represents the temporary condition of the atmosphere at a given place and time, while climate

refers to the general or average condition of the atmosphere. The circulation of the atmosphere is one of the primary factors in bringing about weather changes.

The so-called general or planetary circulation of the atmosphere, brought about by the unequal heating of the earth's surface at different latitudes and modified by the rotation of the earth, is not as simple as it seems, because many factors alter this general picture. For example, the unequal heating of land and water areas during the day and the unequal cooling at night cause disturbances. In the temperate zones in the summer the atmosphere over the land areas becomes heated and the pressure becomes less; the atmosphere over the ocean has a correspondingly low temperature and high pressure. During the winter season these conditions are reversed. Mountain ranges also greatly influence the currents in the atmosphere. The preceding effects are especially marked in the northern hemisphere because of the preponderance of land there.

Most important of all, however, are the frequent storms of middle latitudes which continually disturb the general circulation. The interlatitudinal circulation of air between the heated equatorial regions and cold polar regions does not take place in a regular, unvarying manner but largely by way of great disturbances which give rise to the irregular weather changes of the temperate zones.

Water Is Capable of Existing in the Atmosphere in Vapor Form in Amounts Depending Only on the Temperature.

Water continually evaporates from living organisms and from moist soil as well as from the surface of bodies of water. Evaporation is more rapid when winds are blowing because they carry off the vapor and keep the space unsaturated; evaporation is especially rapid when a hot, dry wind is blowing because the tendency for water to evaporate (vapor pressure) increases with rising temperatures. The maximum amount of water vapor that can exist in a given volume increases with rise in temperature. The more humid the air, *i.e.*, the more water vapor that is already present, the less rapidly will more water evaporate into this space.

The ratio of the amount of water vapor present to the maximum amount possible at the existing temperature, expressed as a percentage, is called the relative humidity. If the air is saturated, the relative humidity is 100 per cent. Under such conditions wet clothes would not dry at all. On a "good drying day" clothes dry quickly, and the relative humidity is low, about 30 to 40 per cent or less; that is, there is present only 30 to 40 per cent of the water vapor that could exist in the same volume at

the current temperature. On muggy days the relative humidity is about 60 to 80 per cent or more. The relative humidity of the air over the oceans is about 85 per cent, the air over the continents averages only about 60 per cent, and that over some of the desert regions drops down to only 25 per cent.

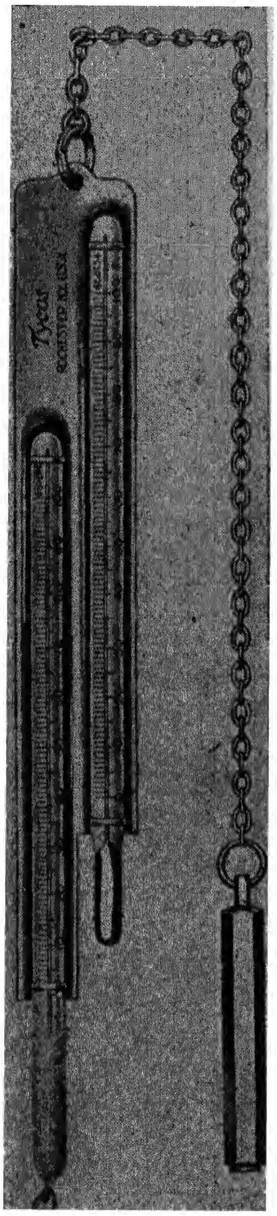


FIG. 78. A sling psychrometer. (Courtesy of Tycos, Rochester, N. Y.)

The amount of this evaporation depends on the temperature, the pressure, and the rate of motion of the atmosphere, as well as the amount and nature of the surface exposed to it.

Relative humidity is measured in a variety of ways. One method is to determine the difference in the temperature shown by a wet and a dry thermometer. Inasmuch as the rate of evaporation from a piece of wet muslin wrapped around the bulb of a thermometer will be determined by the relative humidity, and inasmuch as heat is used up when evaporation takes place, the lowering in the temperature of the wet thermometer will depend on the relative humidity. In the *hygrodeik* the two temperatures are noted, and then, by moving the pointer over the calibrated scale, the relative humidity at a given pressure is indicated. In other cases the two thermometers are whirled; in the sling psychrometer the thermometers are whirled by hand, whereas other psychrometers are whirled by a simple machine.

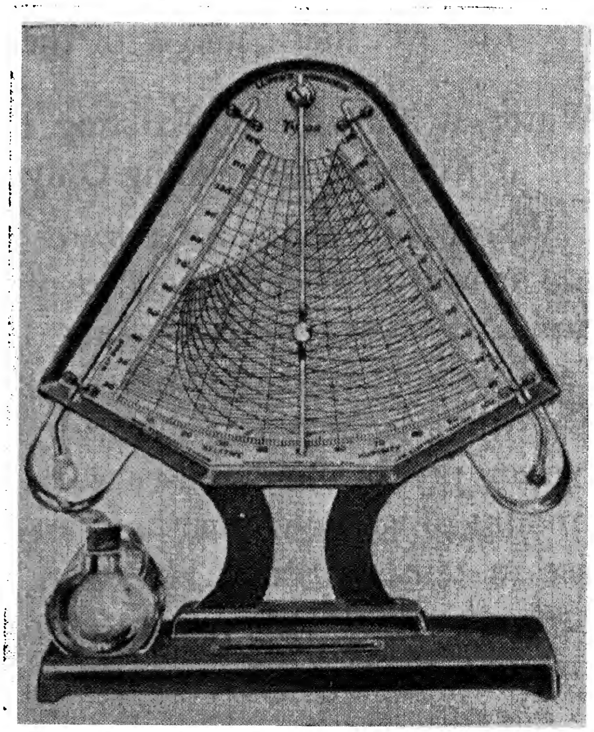


FIG. 79. The Hygrodeik (Courtesy of Tycos, Rochester, N. Y.)

Another type of instrument is the *hair hygrometer*. The American Indians had a gruesome proverb: "When the locks turn damp in the scalp house, surely it will rain." As high humidity does favor rain, this proverb was well founded. The hair hygrometer makes use of the

high susceptibility of human hair to moisture. The hair is treated to remove oils, and then a bundle is fastened in such a way that its changes of length under variations of humidity are shown by the movement of an indicator.

Condensation and Precipitation Are Caused by the Cooling of Air That Contains Water Vapor.

When warm, humid air is cooled, saturation is eventually reached. Any additional cooling will then cause condensation of some of the vapor. The temperature at which condensation will take place is called the *dew point.* The number of degrees that the temperature must fall to reach the dew point depends upon the relative humidity.

Dew does not "fall" but condenses from the atmosphere on objects on the earth's surface which, because of loss of heat by radiation, have cooled more rapidly than the surrounding atmosphere. If the relative humidity is low, there may be no dew. Still, cloudless nights favor dew formation. Clouds radiate heat back to the earth so that dew is less likely to form; while winds keep the atmosphere stirred up and prevent local cooling of the various objects and the adjacent air.

The formation of dew is similar to the formation of the "sweat" on a glass containing ice water in warm weather and the frost on windows and the "sweating" of walls and furniture in an unheated room in the winter, especially in damp climates.

Frost is formed just as dew, except that the condensation occurs below the freezing-point, just as frost forms on the cooling-unit in a mechanical refrigerator or on a windowpane on a cold day.

Fogs and clouds are formed when the temperature of the free atmosphere falls below the dew point. The nucleus for nearly every droplet is a dust particle of some kind on which the water condenses. In the mountains one may climb up into a cloud, which one then calls a fog.

Condensation leading to fogs and clouds may be brought about when a current of warm damp air strikes and partially mixes with a current of cold air. Fog can be cleared successfully under usual weather conditions from a space of sufficient area to be of value to aviation by spraying a saturated solution of calcium chloride into the air, which condenses the fog particles, liberating heat in the process, which further decreases the relative humidity. The most important cause of condensation and the only important cause of rain or snow is the cooling which results from adiabatic expansion [1] of warm, humid air when it is caused to ascend. Heated air at the ground rises because heating

[1] Adiabatic expansion is an expansion in which no heat is added or removed from outside of the system.

makes it less dense and it is forced up by the surrounding cooler air much as a cork is forced up in water; air expands as it rises because of the lower pressure upon it at higher altitudes. Remember that expansion always uses up heat and thus lowers the temperature unless further heat is added. Vertical ascent and descent of air are called *convection.* Convection is also produced when air is forced to flow over mountain ranges or when a current of warm air flows up over a current of cold air. When upward convection of humid air is on a large enough scale, some of the minute cloud particles may grow larger until they become so heavy that they fall as rain or snow. Rain often evaporates before it reaches the earth as it descends to lower altitudes.

So minute are the particles of water in a cloud that a fair-sized cloud would contain less moisture than a glass of water. It is stated that 8,000,000 ordinary cloud particles contain the same amount of water as one ordinary raindrop.

The size of raindrops depends upon the conditions under which they are formed. When moist air rises slowly, very small droplets will fall in the form of a drizzling rain. Sometimes, however, there are strong currents of air moving upward, carrying the droplets with them, catching them up again as they fall, and carrying them up time after time until they grow very large, when they fall in large splashes. Such large drops are often observed just in advance of the downpour of a thunderstorm.

Thunderstorms Are Caused by Intense Vertical Convection.

Thunderstorms result from powerful upward convection currents of highly humid air and are likely to follow a very hot day which has caused strong ascending air currents.

Violent thunderstorms form frequently on the windward side of mountains because the strong winds are deflected upwards by the mountain slopes. Hail often accompanies thunderstorms; the irregular powerful convection currents carry drops of water into the upper cold layers of air, where they freeze and gather coatings of snow and frost, but as they are tumbled about by the turmoil within the cloud they fall back to where the temperature is above freezing and get coatings of water; then they are again carried up, and so on back and forth, gathering additional coatings on each trip, until they become too heavy to be supported any longer and fall as hailstones. When a hailstone is split open, the concentric layers are easily seen as alternate layers of clear and cloudy ice.

Hail is a feature of intense thunderstorms that occur in the spring and summer. Some hailstones have been found that show as many as

twenty-five layers and are very large in size. Hailstorms may be very destructive, ruining crops, killing livestock, and breaking windows.

There are two kinds of thunderstorms; the local thunderstorm generally follows an extremely hot day and moves in no certain path, although the prevailing winds determine its direction somewhat; the more severe thunderstorm is the result of a great current of cold air, often hundreds of miles across, flowing against a current of moist hot air and lifting it bodily by sliding in under it.

Thunder squalls, or line squalls, are often very destructive because of the great velocity of the wind. This wind results from the motion of the huge air mass, in part, but is due chiefly to the outward and downward rush of air produced by the descending current of cold air resulting from the evaporation of the rain.

Thunderstorms occur very frequently in certain mountain regions; for example, on Pikes Peak there is a thunderstorm nearly every afternoon in the summer. Hot, moist regions like those surrounding the Gulf of Mexico have frequent thunderstorms, whereas thunderstorms on the Pacific coast are very rare.

Cloudbursts Are Sometimes Produced by the Conditions That Attend Thunderstorms.

Sometimes rain is prevented from falling by rising air currents until extraordinary amounts of water have accumulated. Suddenly the supporting force weakens, and the water descends as a so-called cloudburst. At Cherrapuaje, India, 40.8 inches of rain fell in one day on June 14, 1876. Here the average annual rainfall is 426 inches, amounting to about 50,000 tons per acre.

FIG. 80. Tornado of May 4, 1922, Austin, Texas. (Courtesy of the U. S. Weather Bureau.)

Tornadoes and Waterspouts Are Violent Whirls in the Atmosphere.

Sometimes upward convection leads to a whirling motion of the ascending column, which may produce, according to circumstances, an ordinary *whirlwind*, a *tornado*, or a *waterspout*. A whirlwind may happen to rotate in either direction and is produced in much the same way as the whirl in water draining out of a basin. On the other hand, the

tornado — the dreaded "twister" of the prairies — always revolves in a counterclockwise direction in the northern hemisphere and is formed only under special meteorological circumstances. The whirl originates at the general cloud level and bores downward toward the ground; the vortex is visible as a writhing funnel-shaped cloud. It is the most violent of all storms; the wind velocity has been estimated, from its effects, to have reached 500 miles per hour in some cases. The rapid whirling leads to a considerable decrease in the atmospheric pressure at the center; and as the center passes over buildings, they sometimes burst outward because of the sudden decrease in external pressure. The powerful upward-spiraling winds often lift heavy objects high into the atmosphere and carry them for long distances. The force of such a wind can be judged by the picture in which a plank is shown to have been driven through a tree. Tornadoes are small, ranging from a few feet to a half-mile in diameter, and generally travel from the southwest to the northeast. One should therefore run to the northwest to avoid an oncoming tube.

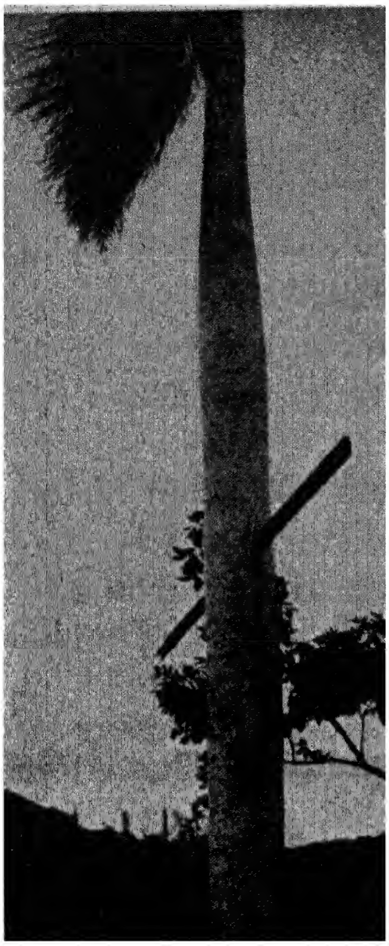


FIG. 81. Royal palm pierced by a pine board, ten feet by three inches by one inch, in the hurricane of September 13, 1928. (Courtesy of the U. S. Weather Bureau.)

Waterspouts are tornadoes or strong whirlwinds that occur over water areas.

FIG. 82. Water spout on Lake Zug, Switzerland, June 19, 1905. (Courtesy of the U. S. Weather Bureau.)

The West Indian *hurricanes* and the Chinese *typhoons* are atmospheric whirls on a larger scale but less intense than tornadoes, having a diameter of from 50 to 500 miles; they are usually more destructive because they are much more widespread and long-enduring. These tropical hurricanes travel at an average rate of about 12 miles an hour, but the winds within the storm approach a velocity of 100 to 150 miles

per hour. A hurricane at Barbados carried a 400-pound piece of lead 1680 feet. The rainfall in tropical cyclones is nearly always heavy, and frequently torrential. One tropical storm may bring enough water so that it would be waist-deep on the level if it did not run off. The Galveston flood of September 8, 1900, which killed 6000 people, was swept into the city by a hurricane. These hurricanes originate only

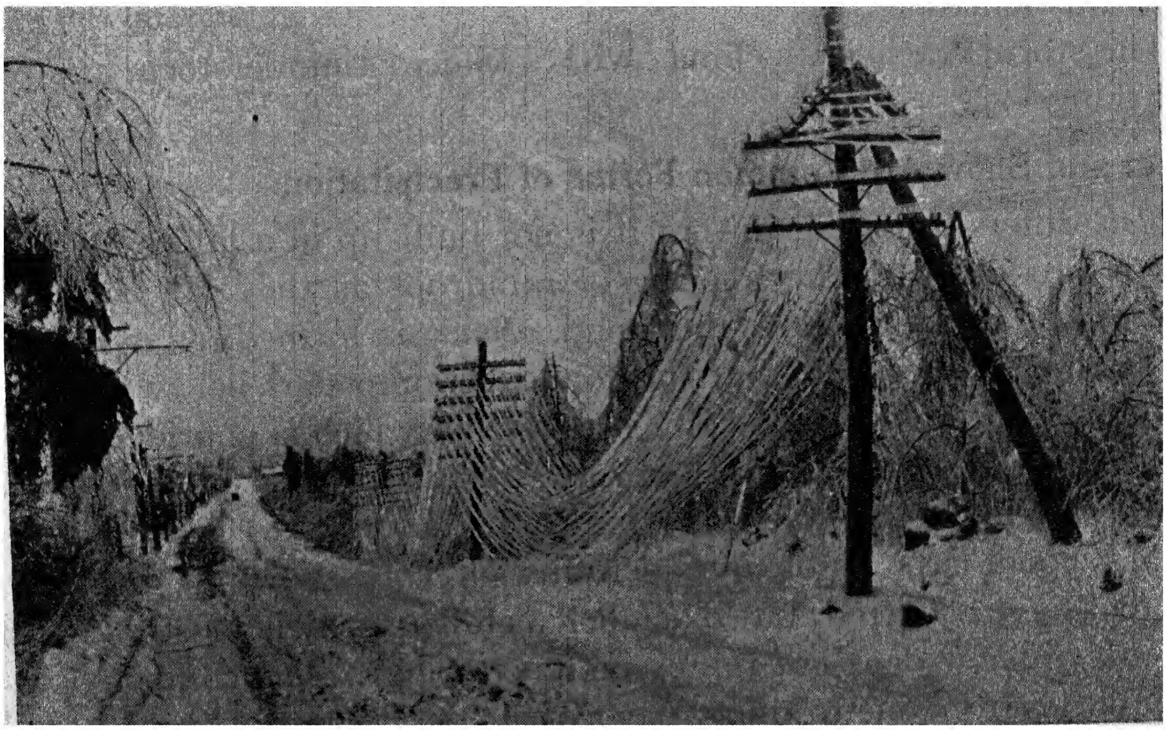


FIG. 83. Sleet storm, New England, 1921. (Courtesy of the American Telegraph and Telephone Company.)

in a few particular areas of the tropics in certain seasons of the year.

On October 7, 1737, a 40-foot storm wave destroyed 20,000 craft at the mouth of the Hooghly River, on the Bay of Bengal, killing 300,000 people. In a similar catastrophe at the same place in 1864, 50,000 lives were lost.

Ice Storms Are Sometimes Very Serious.

Ice storms are the result of rain from a warm layer of air falling onto ground which has been cooled below the freezing-point. Usually a layer of cold air is just above the ground. The warm layer of air above is the result of a cold mass of air pushing under a warm layer, or it may be produced by a warm layer pushing over a cold layer of air.

The Great New England Ice Storm of November 26, 1921, followed days of clear, cold weather that had thoroughly chilled the ground. The storm set in with snow on Saturday, but it soon changed to rain that froze to ice over all the surfaces it reached. On Sunday the thermometer fell to 25° F., and a steady rain Sunday night covered everything

out of doors with an inch-thick layer of ice. On Monday the storm changed to a "northeaster," and during Monday night branches and trees were broken down by the heavy layers of ice and the strong winds. Damage to the extent of millions of dollars was wrought on forests and orchards. Telephone, telegraph, and lighting services stopped as the wires broke under the weight of the two-inch coating of ice. In some places every pole in mile-long stretches of telephone lines was felled.

The storm reached its climax with a violent thunderstorm and pink lightning.

Sleet and Snow Are Common Forms of Precipitation.

Sleet differs from hail in that it is not built up in a layer formation but is produced by the freezing of raindrops as they fall through a stratum of cold air below the cloud. *Snow* is formed, as is rain, by the cooling of moist air, but the condensation occurs below the freezing-point of water. *Graupel* is a white pellet which is considered to be formed by the partial thawing of snow in a warm layer of air, followed by freezing in a lower cold layer of air. The snowflakes grow in beautiful hexagonal crystals of myriad forms. Record snowfalls of three to five feet have occurred; but inasmuch as fallen snow is mostly air, this amount of snow does not represent much water. The composition of snow varies from one to thirty parts of air to one part of water; on the average, ten inches of snow will give one inch of water when melted.

Inasmuch as dark-colored or black surfaces absorb the sun's heat, it is easy to understand that snow covered with soot or ashes will melt much more rapidly than clean white surfaces which reflect most of the radiant energy of the sun.

Heat is given off when condensation takes place, and snow therefore melts very rapidly in a moist warm breeze, because the cold snow causes the moisture in the air to condense. The condensation of moisture equivalent to an inch of rain would melt thirty times as much snow as would the same amount of rain after it was condensed.

It has been suggested that much of the energy of hurricanes is produced by the heat liberated through the condensation of the huge amounts of rain that accompany such storms.

STUDY QUESTIONS

1. Differentiate between weather and climate.
2. Describe an ideal climate.
3. Criticize the climate of your own home locality.
4. What causes the widespread variations in climate?
5. Where are the extremes of continental climatic conditions found? Explain.

6. Explain the equable climates on the western coast of North America.
7. What is the cause of ocean currents?
8. At what time, day or night, do breezes usually blow from the ocean to the land, and why?
9. At what time, day or night, do breezes blow down mountain cányons, and why?
10. How do breezes from the land and sea change from winter to summer?
11. What is meant by relative humidity? How is it measured? Of what value is this information?
12. Why is Death Valley so dry?
13. Account for the Nevada desert.
14. Why does snow melt so rapidly in a moist warm breeze?
15. Discuss the factors which are the basis for climate and weather.
16. Differentiate between whirlwinds, tornadoes, hurricanes, and cyclones.
17. Discuss the causes of rain, snow, fog, lightning storms, and tornadoes.
18. Explain how convection currents are produced.
19. Why do we have less frost in cloudy weather than on clear nights?
20. Discuss the formation of hail.
21. What are the two causes of the circulation of the atmosphere?
22. What is the dew point, and how is it obtained?
23. What is the cause of the excellent climate of Florida?
24. Why do the states along the eastern seaboard experience weather so different from that of the Pacific coast states?

UNIT IV

SECTION 8

SCIENTIFIC WEATHER-FORECASTING IS AN EXCELLENT EXAMPLE OF THE APPLICATION OF THE SCIENTIFIC METHOD

> The belief that nature is orderly is not yet universal. Savages, we are told, live in a completely capricious universe, and we still find congregations praying for rain although they would hesitate, probably, to pray that the sun might stand still. That is because astronomy is a more developed science than meteorology. — J. W. N. Sullivan.[1]

Introduction.

Man has little control of atmospheric conditions beyond the air conditioning of his buildings and trains, but he has learned how to predict the weather fairly accurately for one to two days in advance. In 1940, the United States Weather Bureau launched five-day weather forecasts, issuing them twice a week from ten district headquarters. Weather prediction involves the consideration of so many variable factors and such a large number of observations that it is not at all exact.

Many Observations Must Be Made for Weather Prediction.

At the United States Weather Bureau stations, maximum- and minimum-temperature readings are a part of the regular observational routine. The *maximum thermometer* is like the ordinary kind except that a constriction near the bulb end prevents the mercury from going back to its bulb after it has risen. Just as a clinical thermometer, it must be reset by whirling. The *minimum thermometer* contains alcohol instead of mercury, and it is kept in a nearly horizontal position. As the alcohol recedes with a falling temperature, a little dumbbell-shaped index is carried down with it. Since this index is not carried upward when the alcohol expands, the point where the index is located indicates the lowest temperature reached since the time when the thermometer was last set.

[1] *The Limitations of Science*, The Viking Press, New York, 1934, p. 284.

The *cup anemometer* measures the *velocity of the wind* and records it by means of an electrical-contact system. Dials geared to the shaft read miles per hour directly, while automatic records are made on a time graph in the station every time a mile of wind passes the station. The *wind direction* is recorded every minute by an electrical connection to the *weather vane* and is registered on the same graph.

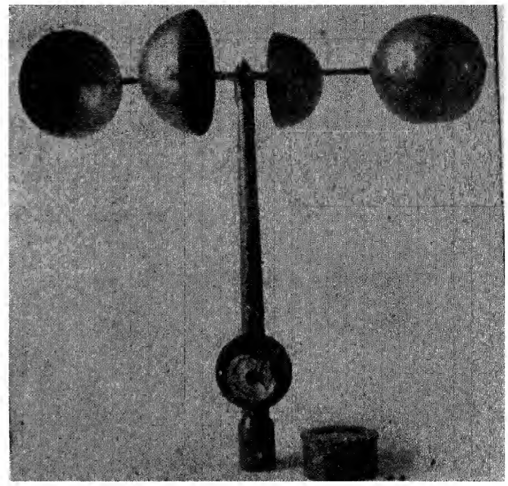


FIG. 84. Robinson four-cup anemometer with cups attached and dial cover off. (Courtesy of the U. S. Weather Bureau.)

The *rain gauge* and the *sunshine recorder* are also provided with electric devices that make it possible to register the amount of precipitation and sunlight on the same graph. The sunshine recorder consists of two bulbs connected by a narrow glass tube which extends down into the lower bulb. The lower bulb is covered with lampblack and is partially filled with mercury. The lampblack absorbs heat and thus expands the air within this bulb, forcing the mercury up into the small tube, sealed at one end and inverted into the mercury. The mercury in the tube closes electrical contacts as long as the sun is shining. The outer tube is evacuated to prevent loss of heat by conduction. The self-recording rain gauge operates by a tiny bucket that tips each time a hundredth of an inch of rain has fallen into it, thus making an electrical contact that operates the recording pen.

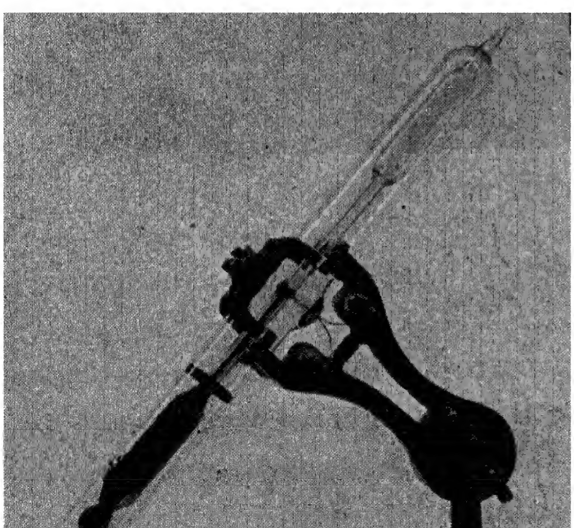


FIG. 85. The sunshine recorder. (Courtesy of the U. S. Weather Bureau.)

Twice each day nearly three hundred skilled weather observers in the United States, Alaska, and the West Indies telegraph their local observations in code to the district headquarters — at 8 A.M. and 8 P.M., E.S.T. Observations of the temperature, barometric pressure, direction and velocity of wind, and the precipitation are telegraphed to these district forecasting stations at Chicago, New Orleans, Denver,

San Francisco, Jacksonville, Kansas City, and Washington, D. C., at each of which they are charted and forecasts made for that district from the charts. Reports are also received from ships at sea, and other reports are interchanged with Mexico and Canada.

At headquarters highly trained men receive and decode the messages. They then chart this information.

The next step is a physical interpretation of the present state of the weather. On the basis of these conclusions and past experience, the

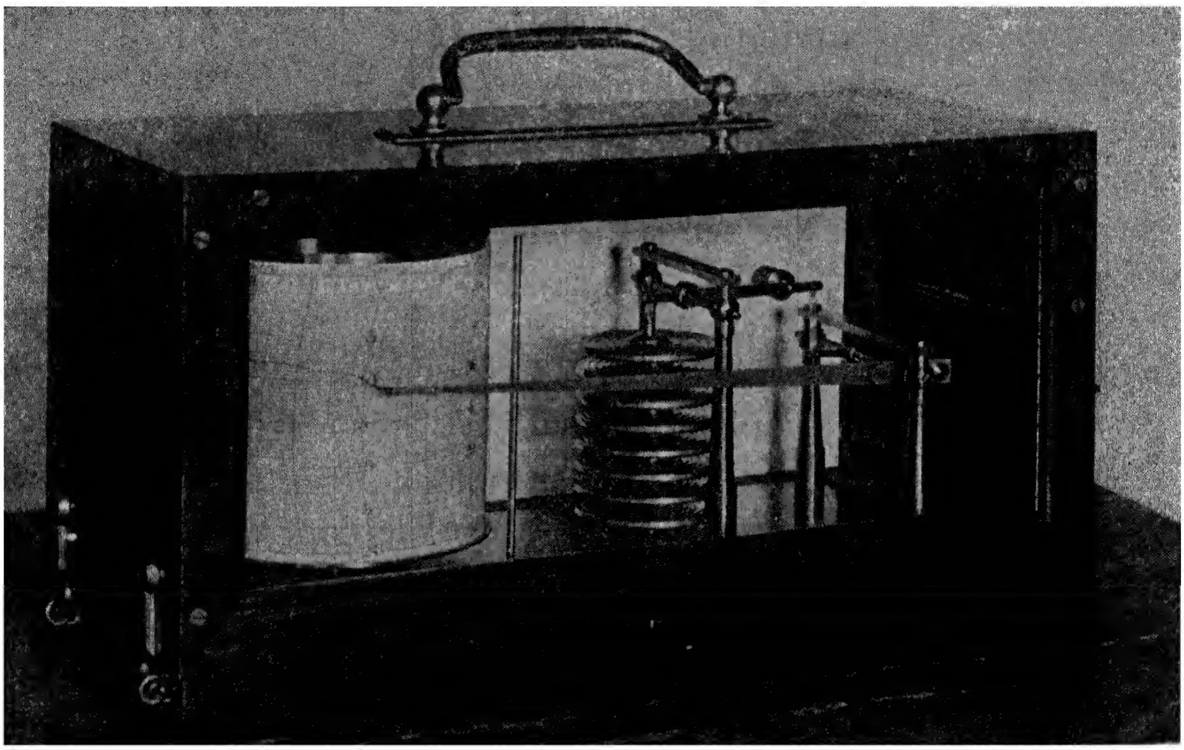


FIG. 86. The aneroid barograph. (Courtesy of the U. S. Weather Bureau.)

weather to be expected for the next twenty-four to thirty-six hours is forecast.

The forecasts of the Weather Bureau are widely distributed from different district headquarters by telegraph, mail, and telephone; the newspapers, radio short wave, and the teletype telegraph machine are also widely used to broadcast coming weather conditions.

Cyclones and Anticyclones Are Charted in Weather-forecasting.

Areas of relatively high barometric pressure, called "anticyclones," and areas of relatively low pressure, called "cyclones," pass over the United States from westerly toward easterly directions, in succession, with speeds varying from about twenty miles per hour in the summer to thirty miles per hour or more in the winter. These so-called *highs* and *lows* cover territories ranging up to more than a thousand miles in diameter. *Highs* generally are accompanied by fair weather, though not always, whereas *lows* usually represent more or less stormy con-

ditions. Dry air is more dense than moist air; the average molecular weight of dry air is 29, while the molecular weight of water vapor is 18. The precipitation of moisture is typical of storms. In the northern hemisphere the winds blow spirally outward in a clockwise direction around anticyclone areas and spirally inward in a counterclockwise direction around cyclone areas; the directions of wind circulation are opposite in the southern hemisphere.

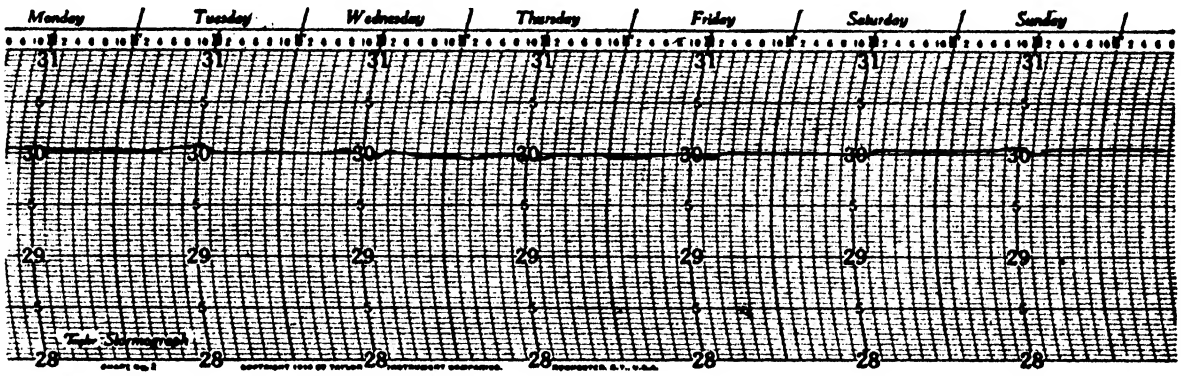


FIG. 87A. An atmospheric pressure record for the week, June 6–12, 1932, at Stockton, California. The weather was fair all week.

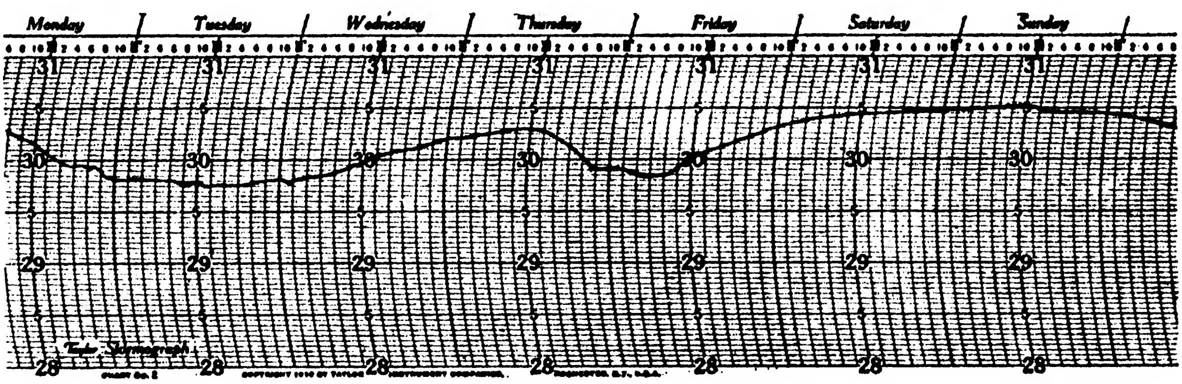


FIG. 87B. An atmospheric pressure record for the week, January 11–17, 1932, at Stockton, California. The weather was stormy during this week.

In general, a storm is approaching when the barometer indicates falling air pressure. The more rapidly the air pressure is falling, the more rapidly is the storm approaching and the more severe it is likely to be.

The indications afforded by the wind and barometer are the best guides now available for determining future weather conditions. In most regions winds from the east and a falling barometric pressure usually indicate foul weather, and winds shifting to the west indicate clearing and fair weather.

The south winds usually bring warmth, the north winds bring cold, the east winds in the middle latitudes indicate a storm approaching from the westward; and the west winds show that the storm has already passed eastward.

During the colder months, when the temperature of the land areas is below that of the ocean, precipitation will take place along the coasts when the wind blows steadily from the water over the land, regardless of the barometric readings, because the moisture in the sea breezes is condensed when they reach cold areas. This is not true during the summer months, however; then the capacity for moisture of the on-shore winds is increased, for their temperature is raised as they blow over the heated land areas.

On the Pacific coast and from the Mississippi and Missouri valleys to the Atlantic coast, precipitation generally starts when the barometric pressure is falling, whereas in the Rocky Mountain region it seldom starts until the pressure begins to rise after a fall. In the summer the showers and thunderstorms in the eastern half of the United States usually come about the time the pressure turns from falling to rising.

A pronounced barometric change indicates a change in weather. If you wish to try your hand at weather-forecasting, study the most recent weather map and see whether a cyclone is headed in your direction or not. Note that it will probably follow the direction of the *isotherm* (line of equal temperature) drawn through its center.

Atmospheric pressure is continuously measured and automatically recorded by the aneroid barograph. Figures 87A and 87B are reproductions of a few records made by such an instrument.

How to Read a Weather Map.

Weather maps show the cyclones and anticyclones at a given time. By joining points of equal pressure, one obtains series of lines, called "isobars," which show the position of cyclones and anticyclones. The United States Weather Bureau now expresses atmospheric pressure in terms of *millibars* rather than inches or millimeters of mercury. One millibar is equivalent to 1000 dynes per square centimeter. The average pressure at sea level (standard pressure) is 1013.2 millibars. Isobars are drawn for every 2, 3, or 4 millibars according to the scale of the map used.

Cyclones and anticyclones follow two more or less well-marked storm routes in the United States. Those coming from the Pacific Ocean move first toward the southeast, then usually swerve in the direction of the Great Lakes, and exit via the St. Lawrence Valley to the sea. The cyclones coming from the southwest travel over the Rocky Mountain region and then move to join those from the Pacific coast in their path to the Great Lakes and the St. Lawrence Valley. Sometimes the *lows* from the southwest bend to the south and traverse the Gulf states

before turning to the Great Lakes. There are many exceptions to this general tendency, depending on the season and other factors.

Cyclones travel variable distances; some are dissipated before they travel far, whereas others traverse entire continents. In February, 1925, a *low* was observed to travel completely around the earth, a distance of 21,379 miles, in about a month's time, before it finally broke up as it started on its second lap.

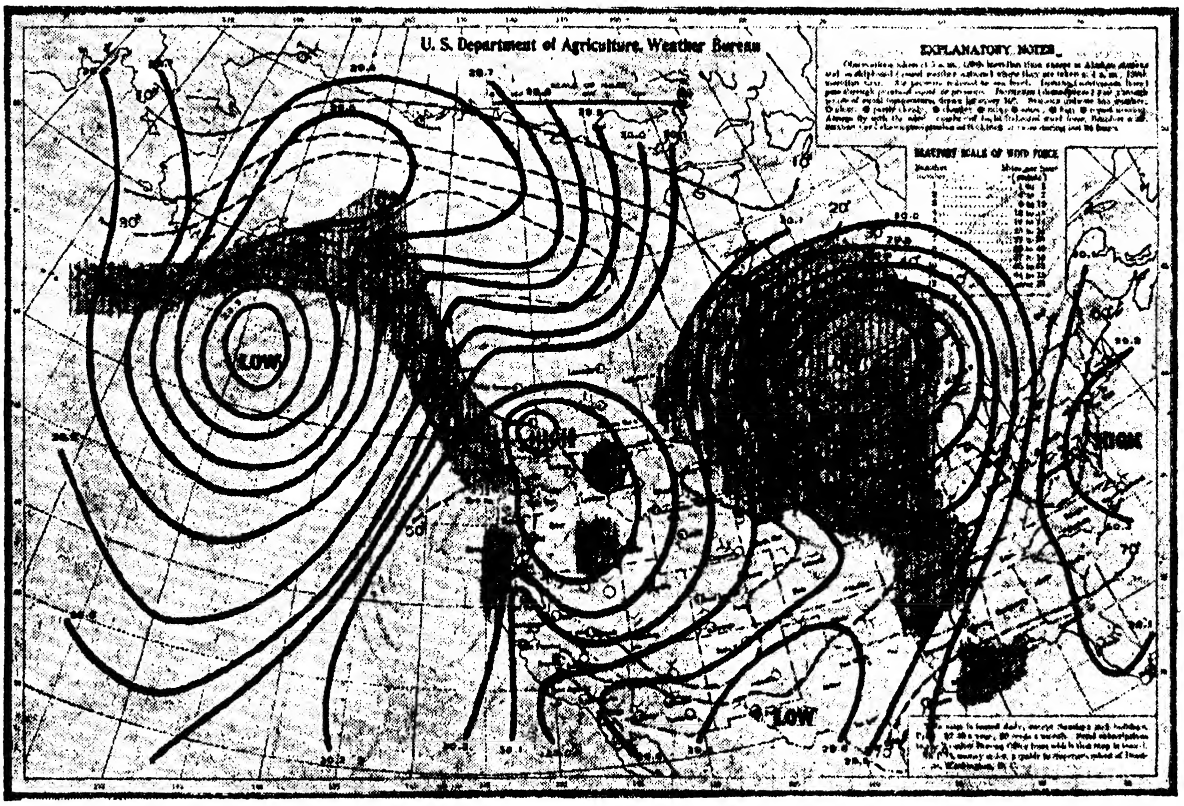


Fig. 88. Weather map retouched to show lines of equal pressure and equal temperature. The heavy lines are lines of equal pressure, while the broken lines are lines of equal temperature. The shaded areas indicate rain. Note the relation between the areas of rain and the cyclones and anti-cyclones.

Though it is uncertain just how cyclones are formed, they seem to involve the contact of large air masses from different sources. An average of about 112 cyclones affect the United States annually. Nearly 45 originate over the North Pacific, 20 over Northwest Canada, 10 over the Rocky Mountain Plateau, 12 over the Colorado Rockies, 15 over Texas and the Western Gulf region, 3 over the Ohio River Basin, and 7 over the Eastern Gulf states.

Cyclones originating in the tropics are usually more violent than those in the other zones. Hurricanes and typhoons are tropical cyclones, 100 to 200 miles in diameter; they originate over warm oceans near the boundary between the doldrums and the trade-wind zones. They move westward or northwestward as long as they remain in tropical latitudes.

It Is Important to Observe the Clouds in Weather-forecasting.

The best known clouds are the fair-weather *cumulus* clouds. These snow-white billowy piles which project upward into the sky have dark, flat bases. In "muggy" weather these clouds become thunderheads.

Stratus clouds are low, flat, foglike clouds of wide extent. Another type is the *nimbus*, from which precipitation takes place. *Cirrus* clouds are very high, wispy, rapidly moving clouds of fine ice crystals. They often appear as the advance guard of a cyclone, having outstripped the

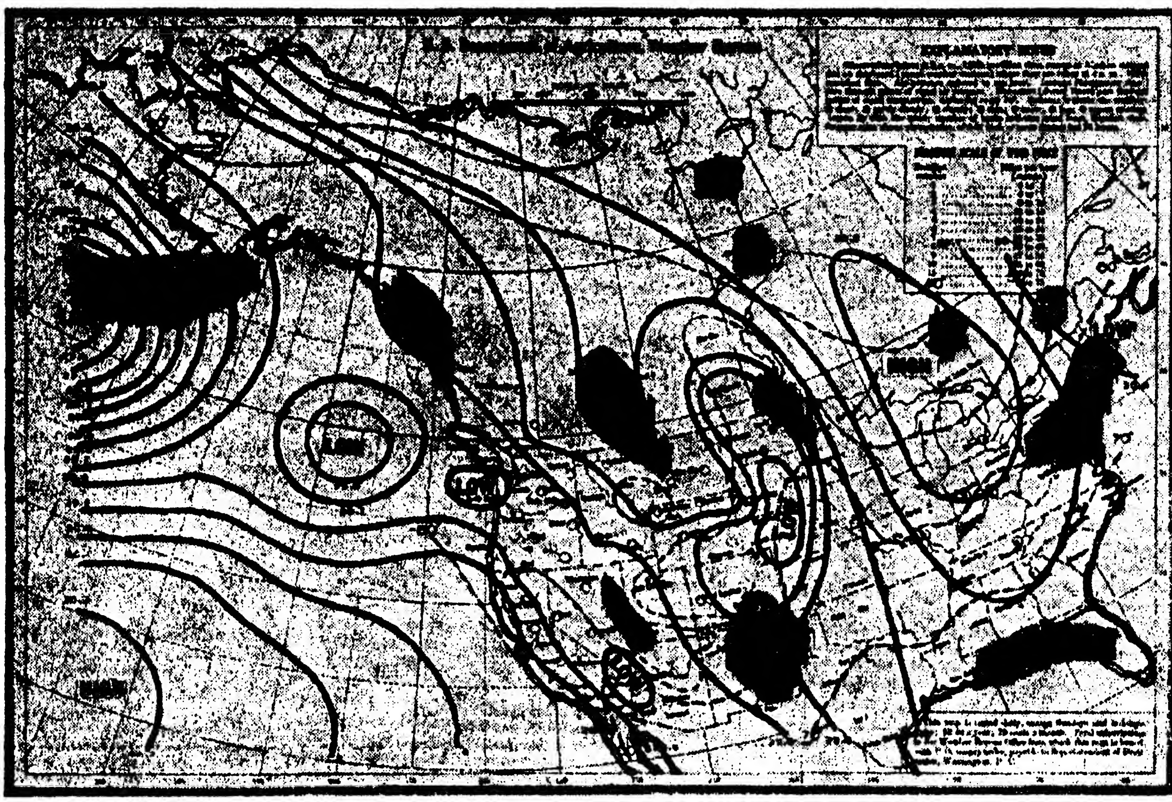


FIG. 89. Weather map retouched to show lines of equal pressure and equal temperature. Compare this map with the one shown in Fig. 88.

storm that is following. As the storm gets nearer, these clouds form slightly lower, extensive, white veil-like layers called *cirro-stratus* clouds.

The *velo* cloud of southern California is the very thick high fog that drifts in from the sea. As it reaches the land, the lower portions are evaporated by the heat from the land, leaving the higher portion to be dissipated later by the heat of the sun.

The Zuñi Indians had an adage: "When the sun is in his house it will rain soon." Large, nearly colorless rings around the sun or moon, known as halos, are produced by the refraction of light by the ice crystals of very tenuous cirrus clouds. The larger the rings appear to be, the closer is the approach of the storm, because the ring, which in reality is always of the same diameter, gives the appearance of an increase in diameter as the clouds come closer to the earth when the storm is approaching.

Air-mass Analysis Is Expected to Improve Weather-forecasting.

Airplanes were formerly used to obtain data concerning the upper atmosphere. The airplanes carried an aero-meteorograph, which recorded the pressure, humidity, and temperature encountered at different altitudes. Adverse flying weather and the time required to ascend to the 16,000 to 20,000 feet at which observations were made limited the use of airplanes. During the past few years the *radiosonde* or radio-meteorograph has replaced the use of the airplane. The radiosonde makes the same observations that the aero-meteorograph did, but it contains a radio transmitter that sends radio signals to a ground receiving station. The radiosonde weighs only two pounds, and one instrument costs less than it costs to make a single high-altitude flight with an airplane. The instrument is carried aloft by a balloon which bursts at very high altitudes; the instrument is carried to the ground by a parachute.

In addition to the use of the radiosonde the direction and force of the wind are noted at many stations by observations of pilot balloons with special instruments called *theodolites.* The *azimuth* [1] and elevation angles are read each minute by the observer and communicated by phone to the computer at the plotting-board in the office. From these angles the wind velocity and direction are computed for various altitudes.

The *nephoscope*, which consists of a black mirror in a circular frame graduated in degrees and a movable sighting eyepiece stand, is used in the determination of the direction and motion of clouds.

The *ceiling* is the distance from the ground to the base of the clouds. At night the ceiling is determined by throwing vertically upward a beam of light from a point five hundred to a thousand feet or more from the point of observation. Knowing this fixed horizontal distance, one can calculate the ceiling from the angular elevation of the spot of light on the cloud from the observing-point. In the daytime balloons are used for ceiling observations. The time that it takes for the balloon to disappear into a cloud and the known rate of ascent of the balloon furnish the data required to calculate the ceiling.

It has been known for many years that extensive masses of air, fairly homogeneous as to temperatures and humidity, often move from certain source regions out over the face of the earth. The weather at any particular place depends largely upon the type of air mass present, the modifications it has undergone in its history, and the way it is interacting with adjacent masses. As these air masses move, they

[1] The azimuth is measured in degrees east or west along the horizon from the south point or the north point.

often lose their homogeneity and contrasts at the surface to the extent that it is difficult to identify them, but it has been found that the upper layers of these moving air masses change less than the lower layers and that certain properties of these upper layers may be used to identify these air masses. This is one of the chief purposes in using the radiosonde.

Weather experts expect forecasting to be greatly improved by this study of the movements of air masses on a three-dimensional scale.

The chief sources of these large air masses are the polar and tropical regions. When air masses from these source regions meet, the warm, moist masses are forced above the cold, dry masses and thus form clouds and precipitation as they are cooled by expansion.

It is these great vertical motions which are responsible for practically all precipitation. Slight precipitation may sometimes take place when air currents of different temperatures are mixed, but this happens on a very small scale compared with the amount of precipitation brought about by the expansional cooling of rising air.

A Knowledge of Meteorology Is of Major Importance to Aviators.

Airplane pilots are advised to avoid flying through thunderstorms. Lightning seldom does any more harm than temporarily blinding the pilot. It is the severe turbulence in thunderstorms and the possibility of hail and icing conditions that may damage the airplane or throw it out of control that cause pilots to fly around thunderstorms if possible. It is difficult to fly over a thunderstorm because the upward convection currents ascend to such high altitudes.

The formation of *ice* on aircraft is caused by flying through rain or cloud particles which are below a temperature of 32° F. Supercooled water droplets exist in the majority of clouds when the temperature is below 32° F. This supercooled water is in a very unstable state and freezes quickly when disturbed. It is possible to form ice at temperatures between 32° and 35° F. because of the expansional cooling of air over the airfoil (wind surfaces).

Formation of ice on propellers and wings decreases the "lift" of the airplane and should be avoided. Some airplanes are equipped with de-icing devices; in some cases small portions of the wing surfaces are heated electrically or by engine exhaust gases. Pneumatic (rubber) covering the leading edges of the wings which can be alternately inflated and deflated causes the ice to break off. Propeller blades may be protected against ice by allowing de-icing fluids to which the ice will not adhere to stream over the blades.

In general, however, the pilot avoids, if possible, layers of air in

which ice will form. Weather predictions and observations made while in flight enable the pilot to know when to expect ice formation.

Weather-forecasting Benefits Man in Many Ways.

Warnings of storms are displayed at more than four hundred points along the coasts and the Great Lakes. A white flag means fair weather, a square dark-blue flag means rain or snow, while a red flag with a black center is the signal to prepare for a violent storm. Two such flags give warning of the dreaded hurricanes. Such warnings enable vessels at sea to prepare for the hurricane as far as possible or make for the nearest port. Millions of dollars are saved by detaining ships until the danger is over.

Frost warnings are very important to market gardeners, fruit-, tobacco-, and cranberry-growers, for they are thus enabled to prepare to save their crops by the use of smudge pots and other means. Transportation companies are enabled to protect perishable shipments en route or to refuse to accept such products for shipment until the danger is past.

Warnings of snowstorms enable highway departments and railroads to be ready with snowplows and decrease or halt traffic if necessary. Sheep and cattle ranches must prepare to protect their livestock against blizzards and heavy snows. Week-end winter-sport carnivals are planned and called off on the basis of weather forecasts.

One of the most important services of the Weather Bureau is that rendered to aerial transportation. The United States Weather Bureau maintains about fifty airport weather stations, while a great many more airports maintain their own weather service.

STUDY QUESTIONS

1 What data are required for successful weather prediction?
2. How far ahead may the weather be fairly reliably predicted today?
3. What is meant by air-mass analysis? Of what value is it?
4. Give a few examples to show the value of weather prediction.
5. What are cyclones and anticyclones?
6. What does a pronounced barometric change indicate? Give a reason for your answer.
7. Discuss the value of the observation of clouds in weather prediction.
8. What causes the ring around the moon? What is its significance?
9. Why is it difficult to forecast weather?
10. How are data concerning air masses at high altitudes collected?
11. Why should airplane pilots avoid thunderstorms?
12. What causes ice to form on airplane wings?
13. What is the ceiling, and how is it measured?
14. What is the radiosonde?

UNIT IV

SECTION 9

MAN PRODUCES HIS OWN WEATHER THROUGH AIR CONDITIONING

Introduction.

The harmful effects of extreme climates and weather on the comfort and health of man and on essential materials sensitive to climatic conditions have driven man to manufacture his own weather. Air conditioning, as this process is called, is one of the latest industrial developments in America, and it has already become a large business.

Complete Air Conditioning Involves Regulation of Temperature and Humidity, Circulation, and Removal of Suspended Matter.

Complete air conditioning cools the air when it is too hot, warms the air when it is too cool, humidifies the air when it is too dry, dehumidifies the air when it is too moist, cleans and filters the air, and circulates the air to assure positive rate of motion. (Air movement cannot be felt in a good, comfort air-conditioning installation.)

Air conditioning makes provision for the introduction of air from the outside, but generally this need not be done in residences or small buildings, in which an adequate amount of outdoor air is added by normal infiltration. The carbon dioxide content of the air in an average building rarely reaches more than two to four per cent of the amount necessary to affect the body adversely.

Paul, a scientist of the Institute of Hygiene, Breslau, placed healthy persons in an airtight compartment of three cubic meters capacity and kept them there for varying periods up to four hours. First he kept the temperature and humidity low in this narrow space. The victims noticed no discomfort. Then the scientist raised the temperature and increased the humidity. Discomfort was apparent at once — depression, headache, dizziness, even nausea. Paul admitted fresh air to the victims through a tube. This air was at the same temperature and relative humidity as the air in the cabinet. No relief was felt by the "victims."

They occupied a miniature "Blackhole of Calcutta," where, as history records, over 100 persons, imprisoned in a hot, humid space approximately 15 feet square, perished in a few hours from this same inability of the air to throw off bodily heat.

Paul then experimented with various methods for relieving the discomfort of those in the cabinet. First he dried the air, then he cooled it, and then he put it in motion with a fan. He made no chemical change in its content, however, but the sufferers were almost immediately relieved.

This revolutionary idea of ventilation proved that the discomfort felt by the persons in the cabinet was due not to breathing, but, primarily, to heat stagnation — inability of air which is too warm, too moist, or too quiet to carry away bodily heat — a vital contribution to the science of Air Conditioning.[1]

FIG. 90. The house on the right has been insulated while the house to its left has not been insulated.

On a hot day with a temperature of 80° F. and a relative humidity of 86 per cent, working capacity is reduced approximately 25 per cent, the appetite reduced 13 per cent, and general discomfort ensues. Ideal conditions for most people are about 75° F. with a relative humidity of about 50 per cent, although the ideal indoor temperature is controlled in part by the outdoor temperature.

The Temperature of the Air Must Be Controlled.

Complete year-round air conditioning must include provision for heating the air in the winter and cooling it in the summer.

The most important problem of indoor weather in the winter is that of maintaining the proper temperature. So important is this problem that other factors are overlooked, with a consequent loss of comfort.

In cold climates the money spent for fuel can be decreased by insulating against loss of heat. It pays to fill in between the walls with

[1] From booklet entitled *This Thing Called Air Conditioning.* (Courtesy of the Minneapolis Honeywell Regulator Company.)

insulating material and to insulate in other ways. Storm windows are great heat-savers, even better than weather stripping.

Indoor air during the winter usually is abnormally dry; air before it has been taken into the house has had most of its moisture removed due to the low temperatures outside.

Of course, cooling may be obtained by cold well water or ice, but this is inadequate where cooling is required over long periods of time.

There are three general methods of cooling air: electrical mechanical refrigeration, steam jets, and adsorption systems.

One of the world's largest air-conditioning jobs, that of the Tribune Tower in Chicago, employs the steam-jet type of cooling-plant. Cooling is obtained by spraying water into vacuum tanks, where rapid

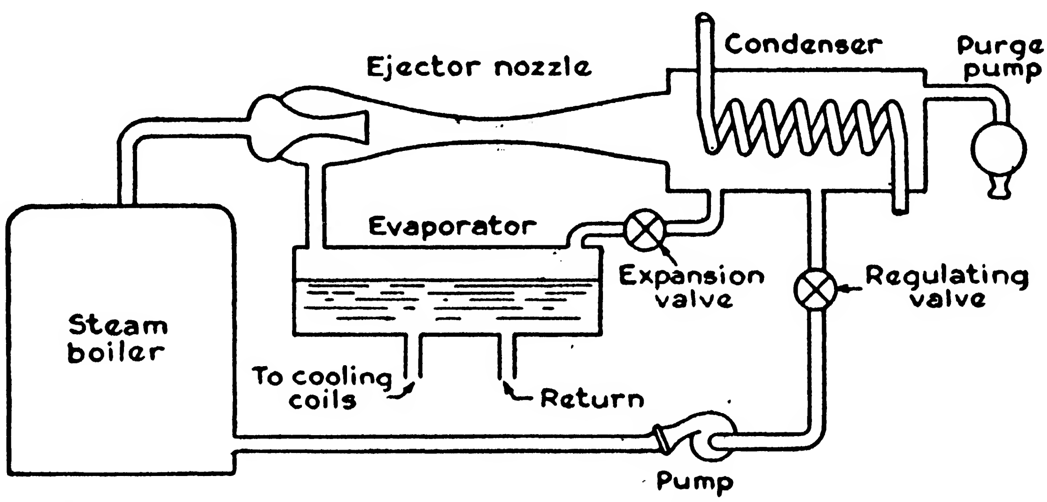


FIG. 91. Steam ejector air conditioning system. (Courtesy of the General Electric Air Conditioning Company.)

evaporation takes place. The vacuum is maintained by jets of steam which are drawn into a chamber where the steam is condensed.

Mechanical refrigeration is the most economical cooling method. The heat required to operate steam-jet or adsorption systems is usually greater than that required to heat the same dwelling in the winter.

A mechanical refrigerating system which is used for refrigeration may be used to cool a house in the summer and heat it in the winter. Thus, by reversing the principle of air-cooling, the outdoor air may be used to heat the building in the winter. Using outdoor air at 35° F., a compressor can raise its temperature to 70° F., expending only one-fifth as much electrical energy as would be required to heat the air by electrical-resistance heaters. Such a heating system can be operated as cheaply as any heating system; but the original cost is quite high, and maintenance costs might be considerably higher.

It will be recalled that a mechanical refrigerating system has two coils, one which cools the air and the other which is cooled by the air or condenser water or evaporative cooling (air and water). The system

is merely a device to transfer heat from one place to another. When a compressor is used to cool a building, the heat is taken out of the building and absorbed by the outside air (or by water as mentioned above), which, though warm, is cooler than the compressed gas.

In the winter the heating coil is used to heat the inside air, while the heat is taken from the outside air which is usually considerably warmer than the cooling-coil.

In adding moisture to the air in the winter, heat is required for the vaporization of the water. The vaporization of water not only adds to

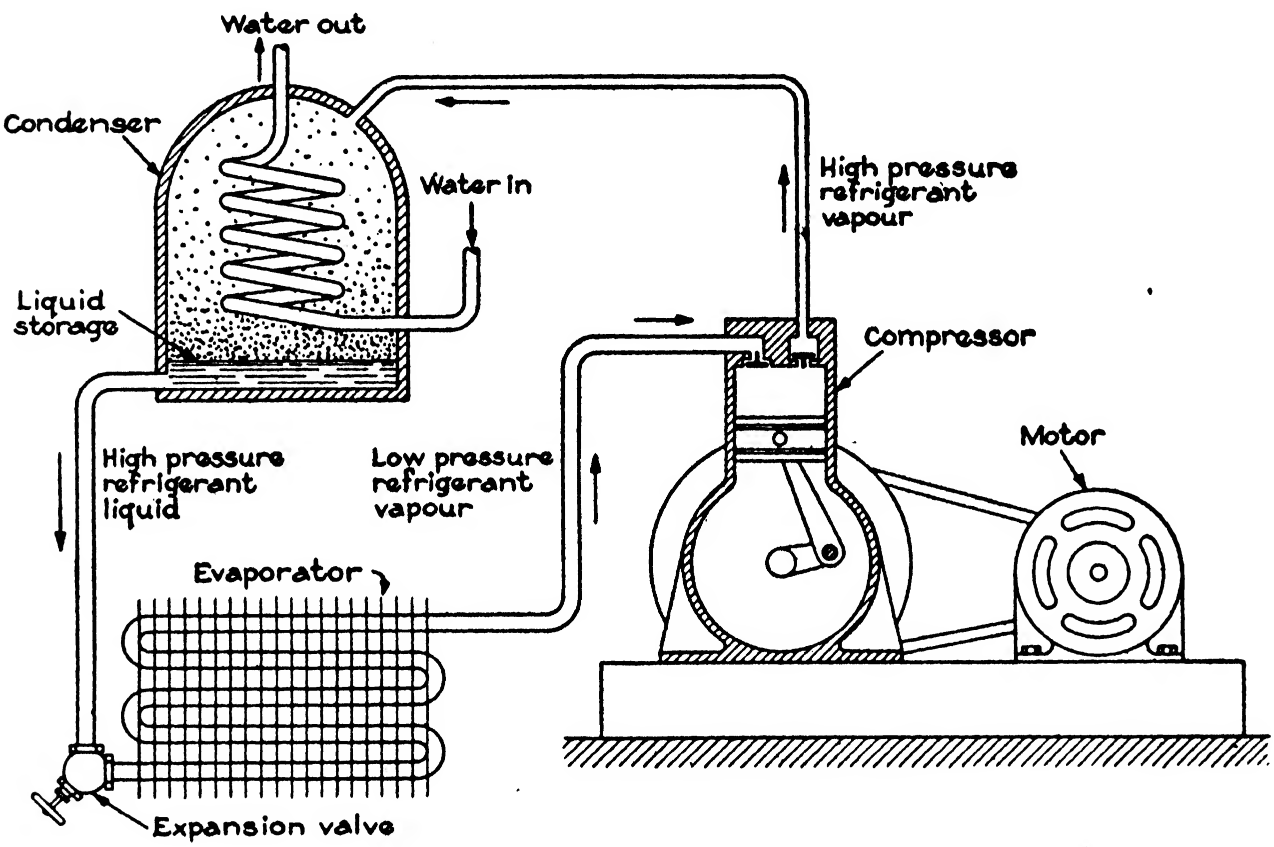


FIG. 92. Vapor compression air conditioning system. (Courtesy of the General Electric Air Conditioning Company.)

the amount of heat required for heating in the winter, but inasmuch as moisture must be removed from the air in the summer and inasmuch as this process of condensation gives off heat, adding to the amount of heat that must be removed, the control of moisture involves the expenditure of energy in either case.

The Humidity Must Be Controlled.

Outdoor air in the winter contains little water because most of it is removed as the air is cooled to low temperatures. If this outdoor air is heated without adding moisture it becomes relatively even drier. We have already pointed out the fact that low temperatures are more comfortable if the relative humidity is not too low. It has been gen-

erally suggested that 68° F. is the ideal temperature. Many people have found that they feel cold at temperatures considerably higher than this in the winter because the humidity is so low.

It is therefore desirable to add moisture to the indoor air in winter. The humidity of the air is usually controlled by passing it through a spray of water, thus adding water to dry air and removing excess water from moist air. Many people do not realize that the humidity of hot moist air can be decreased by passing it through a spray of cold water.

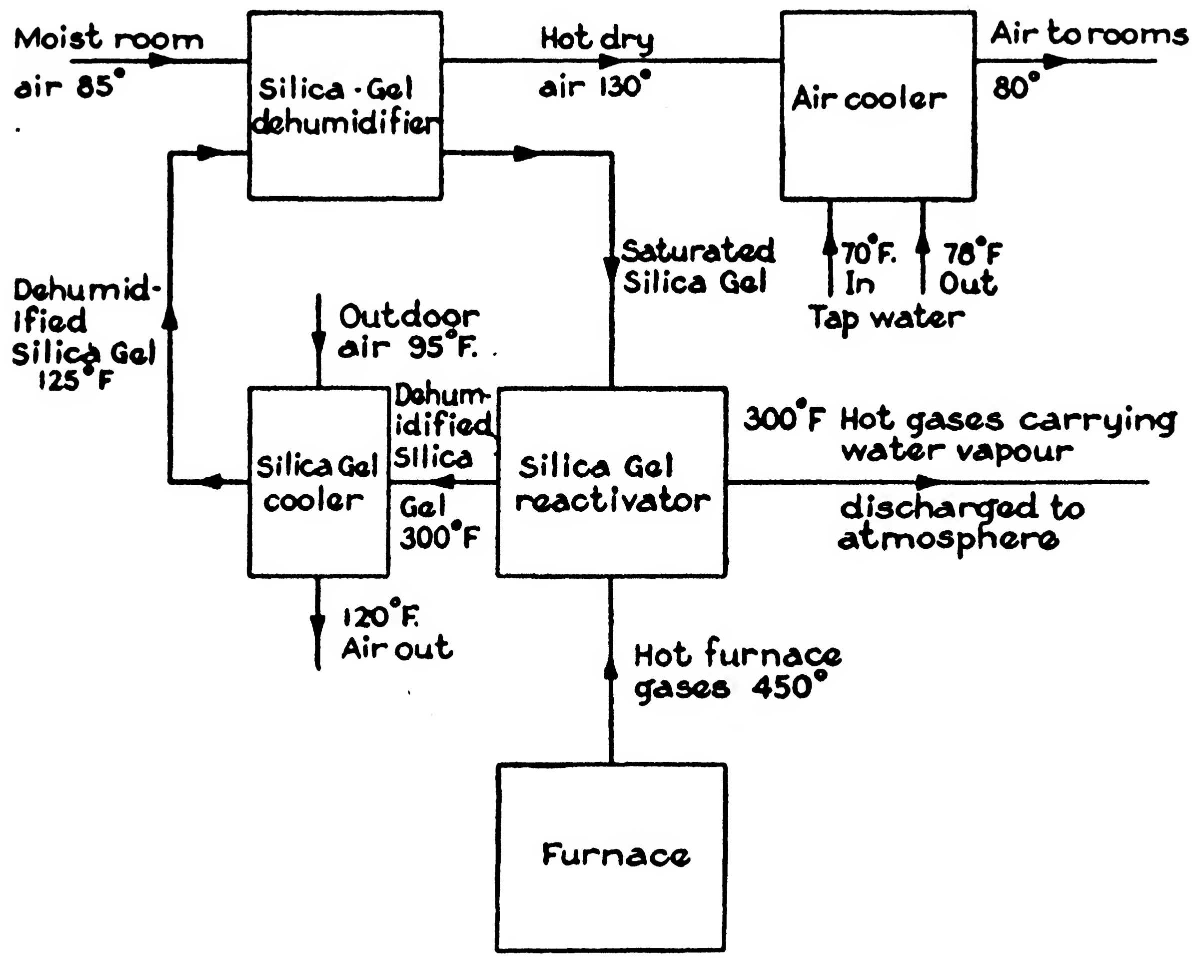


FIG. 93. Silica gel air conditioning system. (Courtesy of the General Electric Air Conditioning Company.)

Various devices for adding moisture in the winter have been used with rather indifferent effectiveness in the past. These devices include water pans in hot-air furnaces, troughs of water heated by radiators, and steam jets controlled by a humidistat.

One ingenious device for the control of humidity depends upon passing air through a spray of a solution of some salt such as lithium chloride. The vapor pressure of this solution can be controlled by controlling the concentration of the salt in the solution, thus making it possible to obtain any desired humidity. Such a solution would take excess moisture from the air and would add the proper amount of moisture to air that is too dry.

Silica gel is used in another successful method of controlling humidity. Silica gel has very high adsorptive power because it exposes a very large amount of surface relative to its mass. The silica gel is placed in a slowly revolving drum through which humid air is drawn and thus dried. At another location hot air is driven through the drum to remove the moisture. An interesting fact to consider is that the humid air is warmed by the condensation of the water vapor on the silica gel — a valuable consideration in the winter, but not desirable in the summer.

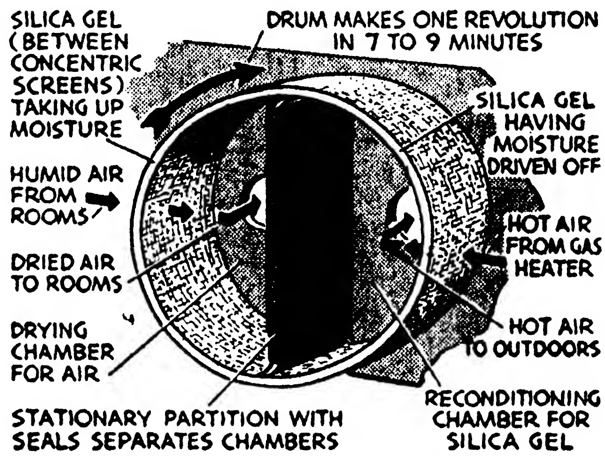


FIG. 94. How the Silica gel dehumidifier works. (Courtesy of *Popular Science.*)

Control of the humidity not only adds to the bodily comfort, but it also prevents the furniture and windows from drying out and cracking. Dry air robs the throat and nasal passages of moisture and renders them more susceptible to colds, pneumonia, and influenza. The air in many homes in the winter is often drier than that in the Sahara Desert. It is the drying of the skin that produces the winter itch that is so annoying to many people. (This itch may also be due to an unusual sensitiveness to cold.)

It has been generally argued that this increase in humidity will lower the fuel bill, but such arguments overlook the fact that the amount of heat required for vaporization of the water to provide this humidity practically offsets the amount of heat saved by maintaining a lower temperature. The amount of water that must be added to the dry atmosphere in the winter to bring the humidity within desired limits is surprisingly large. In an average home it involves the evaporation of gallons of water daily.

The Air Must Be Filtered.

One of the most difficult phases of air conditioning is that of dust and dirt removal. Very small particles are very difficult to remove, although human beings remove nearly 100 per cent of the dust from the air that they breathe. Unfortunately this dust often contains materials which are harmful to the lungs where it accumulates.

As much as two quarts of dirt have been filtered from the air in an average home in one month. The removal of dirt from the air materially reduces the amount of housecleaning and dusting required.

It has been calculated that from 42 to 100 ounces of dust will filter into a 15,000 cubic foot house in a year, under average conditions.

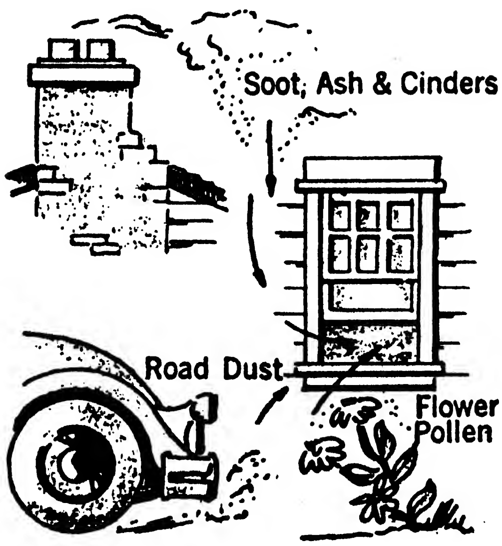


FIG. 95. (Courtesy of Servel, Inc.)

Air is cleaned at the same time that its temperature and humidity are controlled by passing it through a spray of water. In some systems it is cleaned by passing it through a filter of steel wool, or oil-treated spun glass. Filters made of felt and other fine materials are also very efficient.

Another efficient device to remove dust, smoke, and pollens from the air is the "Precipitron" electrostatic air-cleaner. Unfortunately the cost of operation including that of tube replacements makes this method of cleaning rather expensive; but this problem will undoubtedly be solved in time, and for many purposes the expense is more than paid for by the savings due to smaller cleaning bills and longer shelf-life of merchandise.

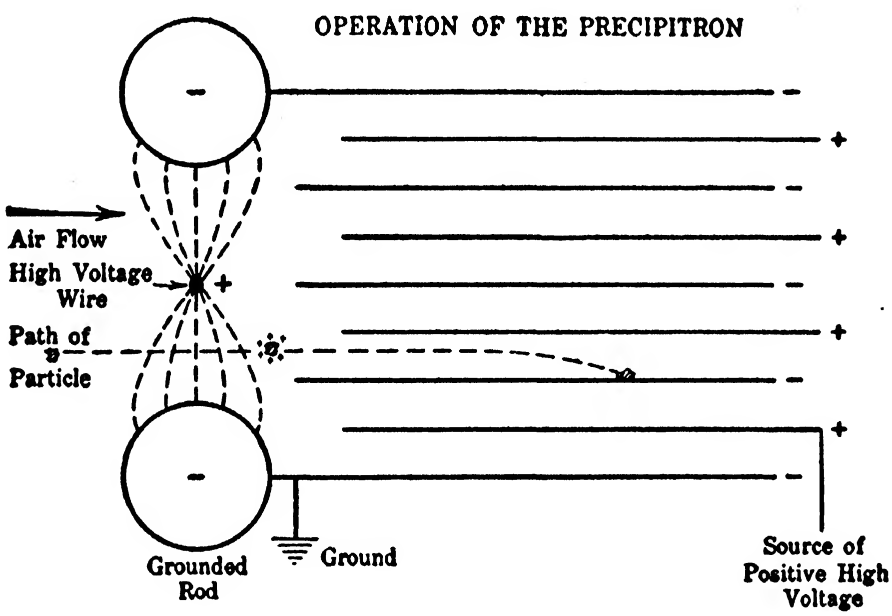


FIG. 96. The principle of the precipitron.

The Air Must Be Circulated.

In homes lacking forced air circulation a person standing erect may be in a temperature of 70° F. at the breathing line, his feet may be at a temperature of about 62° F., and the temperature at the ceiling may be nearly 80° F. This difference in temperature is reduced to only three or four degrees with a circulating system.

The air is generally circulated by means of fans, which may be

operated by the same motors that run the refrigeration units, although separate motors are generally employed.

Air Conditioning First Originated in Certain Industries.

Some thirty years ago it was found that variations in temperature and humidity caused shrinkage and expansion of paper that made fine printing impossible. So perhaps the first genuine attempt at air conditioning was made in printing plants. Air conditioning is also important in textile mills and flour mills to prevent dust explosions and to turn out uniform products. Breweries and distilleries use it to reduce bacterial infection. Food industries find air conditioning valuable. Furniture-makers and automobile-body plants use air conditioning to reduce dust while drying the lacquers and other finishes.

Air Conditioning Has Been Widely Adopted for Large Buildings.

Motion-picture theaters were among the first types of large buildings to be air conditioned. It is a distinct economy to remove the dirt from air in such buildings, thus reducing the cleaning expense and keeping the costly decorations clean much longer. The added feature of refrigeration soon pays for itself by increased patronage in the summer. Frequently it has been carried to an extreme, the air being maintained at too low a temperature for the welfare and comfort of the patrons.

Restaurants, beauty parlors, salesrooms, and retail establishments quickly adopted air conditioning because of its sales appeal; for example, air conditioning in a large eastern restaurant during the summer increased the average patronage 38 per cent and the average sales check 30 per cent. People eat more when they are not too hot.

In 1933 railroad trains were air conditioned for the first time. These trains met with such popular approval that all of the new railroad cars and many of the old ones are now air conditioned.

It has been found that conditioned air not only increases the bodily comfort during the whole year, but as a result of this also increases one's efficiency. Many large office buildings have been air conditioned throughout.

The Department of Interior Building at Washington, D. C., eight million cubic feet in size, was air conditioned at a cost of about a million dollars. Most of the other United States Government buildings at Washington, including the White House, the Capitol, the Hall of the House of Representatives, and the Senate Chamber, have been air conditioned.

The Ford Motor Company has completely air conditioned its huge plant at River Rouge. It has been found that this results in better con-

trol of the accuracy of fine machining operations and provides protection from dust and dirt as well as increased comfort and efficiency for the workmen.

Air Conditioning Is Changing Building Construction.

The cooling load may be decreased as much as 50 per cent in the older types of buildings by use of awnings, circulation of air through the attic, insulation of walls and ceiling, and installing weather stripping.

The Hershey Chocolate Corporation of Hershey, Pennsylvania, has completed a large, three-story general office building without a single window. All external noises are shut out. Lighting is constant and ideal.

Long ago, large stores found that windows represented a loss of wall space. It is possible that, in the future, homes will be built either without windows or with a few immovable double plate-glass windows that will permit the enjoyment of desirable views. The glass bricks which are coming into use for building purposes will permit the home to be lighted during the day without windows.

Insulation, So Important in Air Conditioning, Depends upon a Knowledge of the Three Ways in Which Heat Is Transferred.

Heat is transferred from one place to another or from one body to another by *conduction*, *convection*, and *radiation*.

1. ***Conduction.*** It is a common observation that some materials conduct heat better than others. Cloth pot-lifters and wooden handles are used to handle hot metal utensils because cloth and wood are poor conductors (*i.e.*, good insulators) of heat.

All metals are good conductors of heat, although they differ considerably among themselves. Nonmetals are poor conductors of heat. The conductivities of some common substances, taking copper as a standard, are listed in the following table.

Relative Heat Conductivities

Silver	1.096
Copper	1.000
Aluminum	0.50
Iron	0.167
Mercury	0.0201
Glass	0.002
Water	0.0014
Hard wood	0.0005
Paraffin	0.0005
Alcohol	0.00043
Hair felt	0.00009
Air	0.000057

Heat conductivities are of considerable practical importance. A study of the above table explains why a steel railroad track will be almost too hot to touch on a hot day, while the wooden ties under the track will feel much cooler, assuming equal absorption coefficients. Wood feels cooler because heat is quickly conducted away from it to the skin at points of contact which thus come down to the temperature of the skin. Steel, being a much better conductor, requires that a much greater mass be cooled by absorption by the body before the temperature of the point of contact can be reduced to skin temperature. A rug feels warmer to bare feet on a cold morning than hard wood because less heat is required to warm up the portion of the rug in contact with the skin, partly because the rug is a poorer conductor of heat and partly because there are fewer points of contact. The walls of refrigerators, the walls of buildings, hot-water pipes, ovens, etc. must be insulated to keep heat in or out, whichever the need may be. In other cases good heat conductivity is desired as in the case of cooking-utensils.

Waterless cooking-utensils, which cook food at relatively low temperatures without loss of flavors through escaping steam and without the loss of valuable minerals, vitamins, sugars, and other soluble substances by solution in the boiling water, later to be discarded, are excellent applications of heat conductivity. When thin aluminum or iron utensils are used for cooking, water must be used to conduct the heat from the very hot bottom of the pan to the food to be cooked, because otherwise the food at the bottom of the pan would be burned and the food toward the top would not be cooked. The insides of the bottoms of such utensils are much hotter than in the case of waterless cooking-utensils with thick bottoms. In the latter case, inasmuch as the heat is transmitted almost equally over the bottom, sides, and top of the pan, the utensil acts as a small oven. Incidentally, it might be added that most of the advantages of waterless cooking may be obtained by the use of parchment paper, in which the food is tied up and then cooked in the usual way in a pot of water.

Inasmuch as air is a very poor conductor of heat, layers of air between windows (storm windows) and in the walls of buildings act as good insulators. The minute air spaces in woolen textiles account for their warmth.

Fireless cookers are devices by which the heat used to start the cooking is prevented from loss by conduction so that the heat may thus complete the cooking-process.

2. Convection. The transfer of heat by convection currents of liquids or gases, which results from their expansion and consequent decrease

in density when heated, is an important consideration in air conditioning; for example, adequate provision should be made for the ventilation of the openings between the roof and the house proper so as to provide for the removal of hot air by convection during hot weather.

*3. **Radiation.*** Most of the heat energy which we receive is transferred to us by radiation. The warmth of a fire or of the sun is radiated heat. Air is such a poor conductor of heat that conduction would not account for this warmth. Convection currents in the air move upward from the earth and therefore could not conduct the heat of the sun down to the earth. Furthermore, there is no material in interstellar space by which heat could be conducted or in which convection currents could form.

The presence of radiant energy can be recognized only when there is something present to absorb it. The nature of radiant energy will be discussed in Unit VI. It will be sufficient at this point merely to mention that radiant energy can be transformed into heat and that the heat can be transformed back into radiant energy. A familiar illustration of the latter process is the illumination obtained from an electric-light bulb produced by heating a filament to a high temperature.

It might be well to mention also that rough black bodies absorb and radiate heat better than smooth white bodies.

The vacuum bottle, originally designed by Dewar as a liquid-air container, has found its place in nearly every home; it is a thin-walled glass flask with double walls, so constructed that the air can be removed by a vacuum pump and the air outlet can then be sealed off by melting the glass outlet. The removal of the air produces a partial vacuum which prevents conduction or convection. The walls are made thin to decrease conduction by the glass and to prevent it from cracking from unequal expansion or contraction. One of the walls is silvered. The mirror reflects radiant energy and thus cuts down to the minimum the transfer of heat by radiation.

In planning a home to be air conditioned, attention must be given to radiation because most of the heat that comes through windows exposed to the sunlight enters the house by radiation. One way of controlling the temperature of the people in a house is to use pipes or panels in the floor, walls, or ceiling, covering all areas not occupied by such panels or pipes with reflecting non-heat-absorbing material. By this method the people in the room are heated or cooled by radiation, although the walls, floors, ceilings, and the air in the room are not heated or cooled, with the exception of the radiating surfaces. People would feel cool in a room whose air temperature is 90° when cold water is circulated through the radiating panels, while people would feel

quite comfortable in a room at a temperature of 40° F. when the radiating panels are hot. This method of controlling the temperature should cost much less than systems which depend on heating or cooling the air.

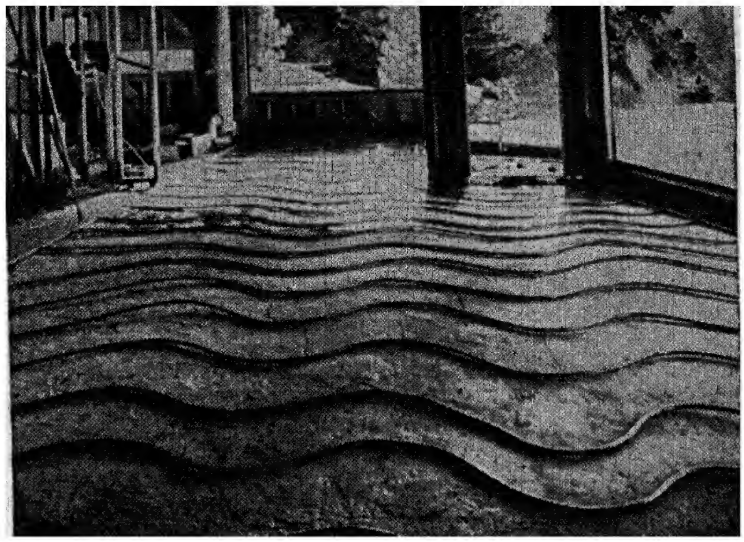


FIG. 97. A floor-warming pipe installation before laying the floor. (Courtesy of the Copper and Brass Research Association.)

Radiant heating and cooling would save money in part because a house would not need to be heated or cooled when one was not in it. Cheap electricity would make it possible to provide comfort within a minute or two after turning a switch.

STUDY QUESTIONS

1. What does complete air conditioning involve?
2. What is new about the recently advertised "air conditioned refrigerators"?
3. Would an "air conditioned" hat have any special sales appeal to you?
4. What is the most common cause of discomfort in crowded rooms?
5. Do you think that one should consider air conditioning in designing a new home today?
6. In what respects would air conditioning change the construction of a new home?
7. Where was air conditioning first introduced, and why?
8. What are the possible social consequences of air conditioning?
9. What is the best way to cool air?
10. What are the advantages of air conditioning?
11. What is meant by a reverse refrigeration cycle?
12. Discuss the advantages of radiant heating and cooling.
13. How may humidity be controlled?
14. Discuss the necessity of insulation in air conditioning.
15. How could radiant heat be kept out of a building?
16. Why should provisions be made for ventilating the space under roofs?
17. How could the direct rays of the sun be kept off window areas during the hot part of the day?

18. Why is there a possibility of condensation of moisture between the walls of air-conditioned houses?
19. Why would it be necessary to decrease the humidity in the air if it were fairly high when using radiant cooling-panels?
20. Why is it possible to obtain five times as much heat from electricity by using it to operate a compressor, rather than by using it in a direct-heating device? Is any heat wasted in an electrical heating device?
21. Discuss the various methods of removing dirt from the air.
22. If you were allergic to pollens, what method of removing pollens from the air would you select, and why?

UNIT V

MAN HAS DISCOVERED AND HARNESSED DIFFERENT FORMS OF ENERGY

INTRODUCTION TO UNIT V

Today every man, woman, and child in the United States has, on the average, more than ten slaves to work for him. These mechanical slaves, operated by the energy which man has learned to harness, are equivalent to ten man-power units of work per person in the United States.

This situation is not true throughout the world, for the 127 million people in the United States accomplish as much mechanical work aided by power machinery as the rest of the 1875 million people on the earth. A one-horsepower motor can do the work of ten or more average laborers for only a few cents a day. It has been calculated that the average American family employs the equivalent of fifteen able-bodied men for forty hours a week, at the total cost of about $75 per year.

It is through the labor of these mechanical slaves that modern man is acquiring more and more leisure time and more and more time-saving devices. These slaves transport him from place to place with ever increasing speed; they dig his ditches, till his soil, reap his crops, prepare his foods, and make his clothes.

These developments have made modern life more complex, because man has to control these machines. As he gains more and more power, it becomes more important that he should determine what to do with it. Shall he use it for war or peace? Shall he use it for exploitation or for the betterment of his fellow-men? What will modern man do with his leisure time? Will it contribute to a more ideal life on earth or not?

These problems did not exist for any man two hundred years ago. His main problems were the elemental problems of securing food and clothing sufficient to keep himself and his family alive.

In past ages, human slavery was common, and even today a few people and nations can gain power, luxury, and leisure by this ex-

ploitation of human beings. Today, man has a greater freedom than ever before; but a new kind of slavery, that of the machine-tender, is possible.

It is important, therefore, that we understand, as far as possible, the nature of this energy that man has harnessed and how he has harnessed it, in order that these modern problems may be faced intelligently.

UNIT V

SECTION 1

ENERGY MANIFESTS ITSELF IN MANY FORMS

Introduction.

Energy is the active agent behind any force, maintaining the force and causing it to do work. Although it is the most comprehensive and fundamental concept of physical science, it cannot be adequately defined. The scientist usually thinks of ***energy as that which may be converted into work.***

Power Is the Rate at Which Work Is Done.

Work is the *product of a force and the distance through which an object is moved by the force.* Whenever an object is moved by a force, work is done; the farther the object is moved and the greater the force required, the more is the amount of work done.

An important consideration in using machines is the *rate at which they do work*, which is the definition of *power*.

James Watt, when working on his steam engine, was forced to measure the power of his engine and invented the horsepower as the unit of work. A horsepower is now accepted as the power required to lift vertically 550 pounds one foot in one second.

Machines, like animals, do not always work at their maximum rate. Thus a 2000-h.p. airplane motor may be called upon to deliver that amount of power only under conditions of maximum climbing with maximum loads. A ½-h.p. electric motor does not consume any more electricity than a ¼-h.p. motor when it is doing work that requires only ¼ h.p. It is a general rule that machines should be capable of delivering much more power than they are usually called upon to deliver because such machines will last longer and develop less heat. No man could work at his highest speed for any considerable length of time, as is evidenced by the exhaustion of a runner at the end of a race.

Electrical power is usually measured in watts or kilowatts; 1 kilowatt equals 1.34 horsepower.

A Number of Important Types of Energy Have Been Recognized.

The following important types of energy have been recognized: sound, kinetic, linear, heat, electrical, chemical, radiant, volume, and surface.

A few score years ago electrical energy was not recognized as a type of energy, although its manifestation as lightning was quite familiar; so it would appear quite possible that there are other forms of energy concerning which we know no more than our distant ancestors knew about electrical energy.

The following sections in this Unit will be devoted to the applications of linear energy, which is sometimes called mechanical energy, in doing man's work. Unit VI will be devoted to the study of radiant energy and sound; Unit VII will take up the study of electrical energy; and Unit VIII will consider chemical energy.

Energy May Be Transformed from One Form into Another.

Everyone is familiar with the most import energy transformations. The radiant energy of the sun is transformed by photosynthesis into the chemical energy of cellulose; cellulose may be burned to produce heat, which may be used to generate steam (kinetic energy), which in turn may be used to operate steam engines (mechanical or linear energy). The mechanical energy of steam engines may then be used to turn a dynamo to produce electricity (electrical energy), and this electricity may in turn be used to produce chemical energy (storage battery), mechanical energy (motor), light (light bulb), or heat (stove).

Most of the energy available to man can be traced back to the sun; but radioactivity, the rotation of the earth, and radiations from the stars furnish additional relatively small amounts of energy not commonly useful, although tidal energy may become an important factor in life some day.

There Is No Gain or Loss of Energy in Any Transformation.

Machines give out only as much work as is put into them, minus the work required to overcome friction and the work required to produce forms of energy which are not useful. For example, the heat produced by an electric-light bulb is seldom useful, and the sound produced by an internal-combustion engine is undesirable and therefore constitutes a problem to be solved.

Good bearings and proper lubrication provide greater efficiency by decreasing friction.

$$\text{Efficiency is the ratio: } \frac{\text{useful output (work)}}{\text{total input of energy}}.$$

When a certain amount of chemical energy is liberated by the oxidation of the gasoline in an automobile, the amount of useful work accomplished is quite small. Some automobiles are more efficient than others, but all automobile engines are quite inefficient. That does not mean that any energy is lost but that a large portion of it is wasted.

Nearly every energy transformation is accompanied by the waste of energy in undesired forms. Thus about 25 per cent of the available

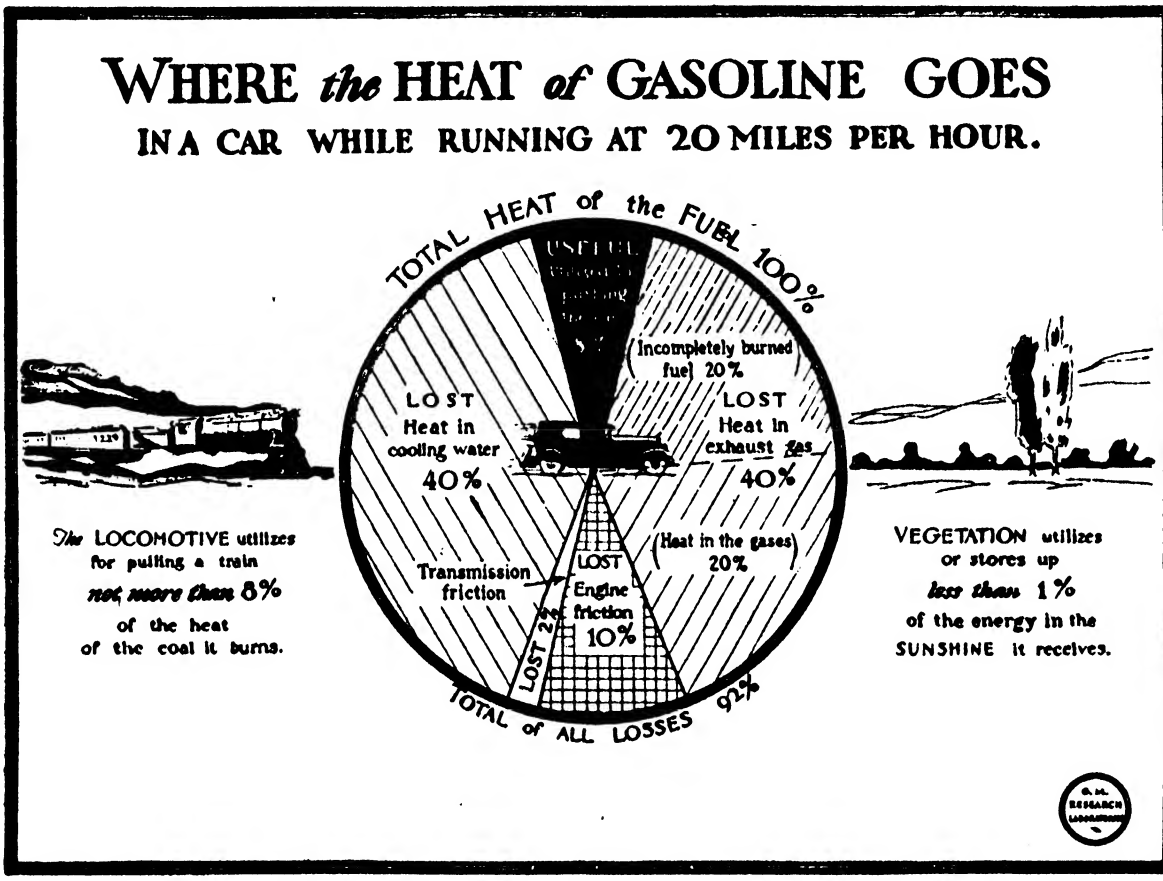


FIG. 98. The automobile is not very efficient. (Courtesy of the General Motors Corporation.)

energy in coal is wasted in various ways and only about 75 per cent is used in the production of steam in a steam engine. About 69 per cent of the energy used in the production of steam is wasted in driving an engine. At least one per cent more is wasted as the engine drives a dynamo. Still more energy is wasted as the electricity overcomes the resistance in a transmission line, and another half per cent is probably lost as it is changed back into mechanical energy in a motor, while an electric-light globe may finally convert only one per cent of the total original energy of the coal into useful light. When all of the energy thus wasted is accounted for, it will be found that the total is the same as the original supply.

Countless other experiments support the law of conservation of

energy; today it is considered to be one of the best established of all of the laws of physics. It may be stated briefly as follows:

Energy is neither created nor destroyed in any of its transformations.

The recent discovery that matter can be changed into energy and energy into matter made it necessary to revise the law of conservation of matter and to cease to think of matter and energy as separate entities, for it was shown that matter is merely a form of energy. The discussion of this form of energy is reserved for Unit VIII.

Energy Is Usually Measured in the Form of Heat.

Other forms of energy are more readily and more completely changed into heat energy than into any other form; for that reason, and because heat can be readily measured, all forms of energy are usually converted into heat for measurement. Energy may also be measured in terms of the work that it will do.

Heat Is Generated by Many Different Methods.

Heat may be produced by mechanical effects, such as friction, percussion, and compression. Cutting-tools often become red hot when they are cutting iron at high speed. An emery wheel produces a shower of red-hot sparks. Railroad rails become heated by the passage of a train over them, while automobile brake bands sometimes catch fire in going down steep mountains. Babbitt metal melts out of connecting-rod bearings when friction is increased due to inadequate lubrication. Heat may also be produced by pounding on a nail. All of these changes represent the transformation of mechanical energy into heat.

The reduction of friction is one of the most important problems in the construction of machines. Ball bearings and roller bearings reduce the amount of friction because they reduce the area of the surfaces of moving objects which touch each other and substitute rolling for slipping. Lubricants reduce friction by forming slippery films on the surfaces of moving objects. Modern motor parts are highly polished to reduce friction.

Friction is often useful. Brakes depend upon friction for their operation. Nails hold in wood, and automobile tires cling to the road because of friction. Volcanoes are sometimes produced by the heat resulting from the friction involved in diastrophism.

Heat may also be produced by changes in the composition of matter. Every chemical reaction is accompanied by a heat change, and certain chemical reactions constitute the chief sources of heat. When oxygen combines with different elements, heat is evolved. Such a chemical

reaction is called oxidation. The oxidation of the foods in our bodies produces body heat and other forms of energy. The oxidation of coal, wood, petroleum, and natural gas produces most of the heat used to run our machinery and to heat and light our homes.

Heat is produced by electricity. Most electric heating devices produce heat by passing the electric current through wire which offers high resistance to the passage of the current and therefore becomes hot.

Heat may also be produced by radiant energy. The radiant energy from the sun is, of course, our ultimate source of heat. It is more convenient to change radiant energy into chemical energy in the form of food or fuel and then burn the substances so formed, than it is to transform light directly into heat.

Heat Is Measured by Means of Calorimeters.

The calorie is the amount of heat required to raise the temperature of one gram of water one degree centigrade. A calorimeter is simply a vessel in which we measure the change in the temperature of a given weight of water by the application of heat under such conditions that but little heat is lost by radiation.

A thermos bottle makes an excellent calorimeter for the measurement of the specific heats of metals or the heat evolved by certain chemical reactions. The product of a change in temperature and the number of grams of water undergoing the change gives the number of small calories. The large Calorie, written with a capital C, is equal to 1000 small calories.

The calorie is used in most scientific measurements, but the quantity factor of heat still used by engineers in the English-speaking countries is the B.T.U. (British thermal unit), which is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Inasmuch as coal is bought for its heating value, many consumers of large quantities pay for it on the basis of its calorific value. Coal, fuels, foods, and other organic substances may be burned in compressed oxygen gas in a bomb calorimeter to determine their calorific values.

Large, roomlike calorimeters have been employed to measure the number of calories used up in sleeping, thinking, exercising, etc.

Thermodynamics Deals with the Conversion of Heat into Mechanical Energy and Vice Versa.

The First Law of Thermodynamics. The first law of thermodynamics, stated non-technically, is: "Something cannot be obtained

for nothing." It is the law of conservation of energy. A more technical statement of the first law of thermodynamics is that in the transformation of work into other forms of energy and in all energy transformations there is no gain or loss of energy.

No scientist would ever consider any scheme that involved "getting something for nothing." Many inventors, unaware of this fundamental principle, have attempted to devise perpetual-motion machines; and the average person would not be greatly surprised to see one in operation, although he would be attracted by the novelty of it. A perpetual-motion machine is a machine that would do work indefinitely without the expenditure of energy. The first law is based in part on man's consistent failure to construct a perpetual-motion machine. A machine that would continue to move indefinitely without doing work is impossible, because a perfectly frictionless machine cannot be built and friction always decreases the mechanical energy with the formation of heat.

The Second Law of Thermodynamics. The second law of thermodynamics, stated non-technically, is: "Everything in the universe tends to run down." A clock always runs down. Water runs downhill and never up, unless an outside force is brought into play. A bullet gradually loses speed and never gains speed after it has been fired. A human being grows old but never grows younger physically. People who realize the significance of this law would seek help from sources of power greater than they possess. They would seek to associate with people of greater ability and development if they really wanted to grow themselves. *Gilbert N. Lewis* expressed the statistical nature of the second law of thermodynamics when he stated, "Stripped of its finery we find that the second law states that if a pack of cards is thrown into a shuffling machine the chances are that it will become shuffled." The thought that Mr. Lewis thus expressed is that any system left to itself approaches a definite state of equilibrium. This law implies that the universe is running down and will eventually come to a dead stop, but some people believe that additional knowledge will show that the universe is not running down. At present there is nothing that we can do about this problem; and it is unimportant anyhow, so we will not pursue it further.

Technically, the second law of thermodynamics states that *heat energy tends to flow from a higher to a lower temperature and will not flow by itself from a lower to a higher temperature.* In other words, heat, just as water, does not flow uphill.

The consequences of thermodynamical reasoning have not only enabled the engineer to design more efficient heat engines, but they

have aided progress in many branches of physical science, ranging from atomic structures to weather-forecasting.

To transform heat into work, heat engines are employed. All heat engines utilize the energy of expansion of gas as it does work in overcoming the force opposing this expansion.

The efficiency of heat engines becomes greater the greater the temperature drop. This conclusion, based on the second law of thermodynamics, has led to the use of superheated steam in boilers at extremely high pressures. Boilers built to withstand these very high pressures are much more efficient than the lower-pressure boilers. As a result of the application of this principle, railroads have greatly increased the efficiency of their locomotives.

Higher efficiency cannot be obtained practically by lowering the final temperature in a heat engine because it requires the expenditure of energy in refrigeration to lower the temperature below that of the atmosphere or the nearest large body of water. Increasing the pressure in steam boilers produces higher initial temperatures, but the increase in efficiency thus made possible is obtained only at the expense of using very strong materials to withstand the high pressures produced.

Mercury has been used to replace water in a few installations because it has a higher boiling-point than water and thus makes it possible to produce higher temperatures without such correspondingly high pressures. Unfortunately, mercury is quite expensive, and its vapor is very poisonous to breathe.

Dowtherm, a mixture of diphenyl and diphenyl oxide, manufactured by the Dow Chemical Company, is now replacing water in some boilers because it boils at 500° F., as compared with 212° F., the boiling-point of water. Dowtherm vapor at 650° F. has a pressure of only 53 pounds per square inch, as compared with 2200 pounds per square inch for steam at the same temperature.

STUDY QUESTIONS

1. How many mechanical slaves per person are there in the United States today? How many of them do you think have been unemployed? Why?
2. Why is it that modern man has more leisure time?
3. What important problem has man's machines presented to him?
4. Define energy and work.
5. State the law of conservation of matter.
6. What is the most convenient form of energy to measure?
7. List all the forms of energy that you can think of.
8. Describe all the energy transformations that may be observed in your own home

9. What is the true nature of heat energy?
10. List four different methods for the production of heat.
11. How are the two factors of heat energy measured?
12. State the first two laws of thermodynamics.
13. Why is a perpetual-motion machine impossible?
14. What is meant by the term "work"?
15. What is power?
16. Why is it desirable to use engines or motors which will deliver more power than is generally required?
17. If a 10-h.p. engine and a 100-h.p. engine each had the same weight and each one were to be placed in an identical chassis, would one engine use more gasoline than the other engine in climbing a 10-mile grade provided only 5 h.p. were required to climb the grade? Why or why not?
18. What is a horsepower?
19. What becomes of that portion of the energy supplied to a machine that does not do useful work?
20. How is friction eliminated in machinery?
21. Why is friction such an important problem in the construction of machinery?
22. Prepare a list of useful applications of friction.
23. Why should one use low gears rather than brakes of an automobile in descending a long steep grade? Where is the friction produced when using low gears? Why is the friction produced when descending in low gears less harmful than that produced when using the brakes?
24. Classify the following examples of energy: (*a*) a speeding automobile, (*b*) a glacier, (*c*) the solar system, (*d*) hot water, (*e*) dynamite, (*f*) sugar.

UNIT V

SECTION 2

THE PRUDENT UTILIZATION AND CONSERVATION OF OUR ENERGY RESOURCES ARE AN IMPORTANT SOCIAL AND ECONOMIC PROBLEM

He that invents a machine augments the power of man. — Beecher.

Introduction.

On June 30, 1934, President Franklin Delano Roosevelt established The National Resources Board

> to prepare and present to the President a program and plan of procedure dealing with the physical, social, governmental, and economic aspects of public policies for the development and use of land, water, and other national resources.

On March 15, 1938, President Roosevelt wrote a letter to the Chairman of the National Resources Committee, which succeeded the National Resources Board and the National Planning Board, in which he stated,

> the need for a comprehensive study of our energy sources, their prudent utilization and conservation, and their competitive relation to each other and to the national economic structure becomes increasingly evident.

The power that operates the machines of our industrial civilization has been millions of years in the making, "and every ton of coal used, every barrel of oil used, and every cubic foot of natural gas used is so much wealth drawn from nature's storehouse."

The consumption of power per capita in the United States is 50 per cent higher than that of Great Britain, more than twice that of Germany, and more than ten times that of Japan.

Bituminous coal supplies 48 per cent of the power; anthracite coal, 6 per cent; petroleum, 32 per cent; natural gas, 10 per cent; and water power, less than 4 per cent. Water power is the only energy resource that is wasted if it is not used and that continually renews itself.

In June, 1939, The National Resources Committee published a booklet, entitled *Our Energy Resources*. This Section is based on the above report. In this booklet, the committee states:

> The time has come to take a broad view of these many power producing resources, to recognize more fully than has been possible in the past that each of these energy resources affects the others. . . . The question is whether the nation shall permit this exploitation to continue without regard for waste, for social objectives, and for future welfare — or shall endeavor to guide it into ways that are more effective for both economic and social objectives than those followed in the past.

Conservation of Energy Resources Involves the Elimination of Waste, the Improvement in the Production of Energy, and an Increased Efficiency in the Utilization of Energy.

Our coal reserves will not be exhausted in many years to come, but it will not be many years until the price of coal will increase because of the depletion of the richer and more accessible deposits.

Known reserves of petroleum and natural gas may last a century or more, but in a decade or two a shortage may increase the cost of these energy sources.

Water power, at best, can never supply more than one fourth of our yearly energy requirements; and the maximum use of water-power resources is not economically feasible because of their poor location relative to the location of power consumption.

Conservation of energy resources is therefore chiefly a problem of elimination of waste and more efficient utilization.

More Efficient Recovery in Production Is Needed.

In the petroleum industry from 80 to 90 per cent of the oil was left in the ground in the older fields. Research has shown the petroleum industry how to recover a higher percentage of oil from the ground, but from 50 to 70 per cent is still unrecoverable.

In underground coal mining 35 per cent of the original deposit is lost, although at least 20 per cent represents an avoidable waste.

The American people should demand more efficient automobiles before high gasoline prices make them imperative. The time to save fuel is while we still have it.

More Efficient Utilization of Power Is Needed.

The average consumption of coal by public-utility power plants has decreased from 7.05 pounds of coal per kilowatt-hour in 1899 to 1.42 pounds in 1937. The best modern stations can produce a kilowatt hour from 0.8 pound of coal. The increase in boiler efficiencies of

from 60 to 92 per cent has saved a great deal of coal for many industries, including the railroads, so that today less coal is required than was utilized ten years ago; and as a result there are too many coal miners. Overproduction and underemployment have meant lowered living standards for coal miners and have resulted in disastrous strikes that lowered the living-standards of every American. Conservation of energy resources must, therefore, be accompanied by a program of planned conservation of human resources; this is a problem which has engaged the attention of the United States Government for some time. The 1937 Coal Act provides for fair minimum prices and prevents unfair competitive practices. It is probable that full public control of power resources will eventuate, if present trends are continued.

The individualistic competitive profit system cannot supply the planning and organization of the conservation of our energy resources that is required. National Defense requires more than a hit-or-miss development of our power resources, as was so well illustrated in the summer of 1941, when the eastern states experienced a gasoline shortage due to the diversion of oil tankers to Great Britain or in the summer of 1942, when enemy submarines reduced the shipments of oil by tankers. Pipe lines could have supplied this needed oil, but other transportation and tanker interests successfully fought the laying of such pipe lines several years previously. In this connection one might well recall the tremendous fight put up by the railroads to prevent the laying of the first pipe lines in the United States.

The Use of Less Valuable Fuels Should Be Encouraged.

The fuels which are easiest to obtain and most convenient to use are those which are being depleted most rapidly, as would be expected. By utilizing less valuable fuels whenever possible, the time of depletion of the more valuable fuel sources and the resulting higher prices may be delayed.

A great deal of research needs to be carried out on the economical utilization of the less valuable fuels, and it follows that the United States Government should sponsor such research.

Water Power Should Be Harnessed.

The great dams in the T.V.A. project, Boulder Dam, and the Grand Coulee Dam are tremendous monuments to the planning ability of our government and the technical ability of our engineers. Each one of these dams represents a significant addition to our national wealth. More projects of this type should be developed, because

every kilowatt-hour of electrical energy produced by water power saves not less than three quarters of a pound of coal or its equivalent.

When finished, the Grand Coulee Dam will develop 2,700,000 horsepower, more than all the present dams of the T.V.A. system. A ten-dam system, of which the Grand Coulee Dam and the Bonneville Dams are a part, could produce more than two per cent of the power requirements of the United States.

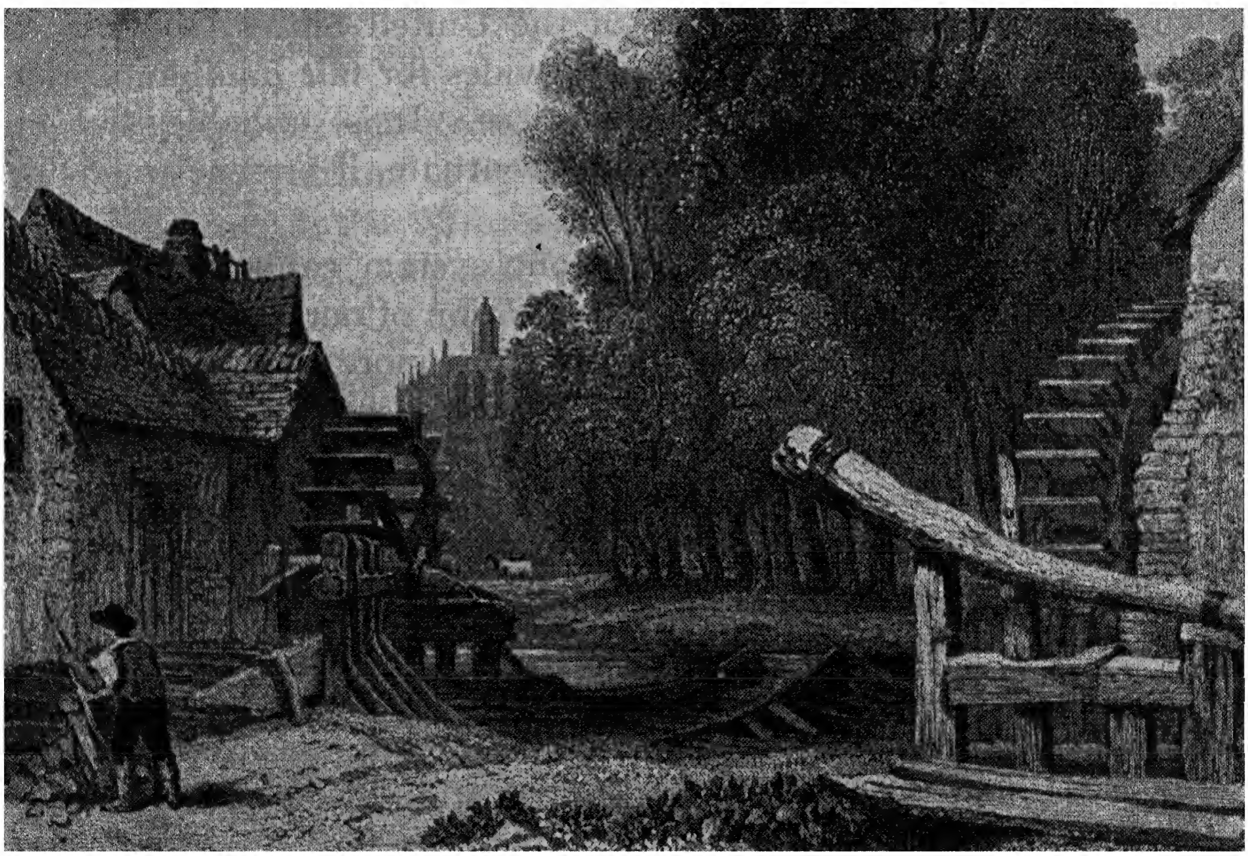


FIG. 99. Water mills at Eul, France. Water-wheels were used before the industrial revolution.

The Connally Act and the Interstate Oil Compact Regulate the Petroleum and Natural-gas Industry in the Public Interest.

Practically 100 per cent of the energy requirements of automobiles and airplanes are derived from petroleum; 93 per cent of the tonnage of ocean-going vessels of the United States Merchant Marine is moved by oil, and practically all of the United States Navy vessels are powered by petroleum products. A high per cent of agricultural work is done by tractors and other machines which use petroleum products for power.

Since 1924 the United States Government has indicated that the private operation of the petroleum industry should be in line with public welfare. The Connally Act prevents the interstate or foreign shipments of oil produced in violation of State laws. The Interstate

Oil Compact is a treaty, approved by Congress, between a number of oil-producing states authorizing them to work toward uniform conservation laws. Several important oil-producing States did not enter the compact, and some of the States that did enter the compact do not have conservation laws. It seems quite likely that Federal regulation of the production and distribution of petroleum and natural gas will have to come soon in order to prevent the waste of this irreplaceable resource.

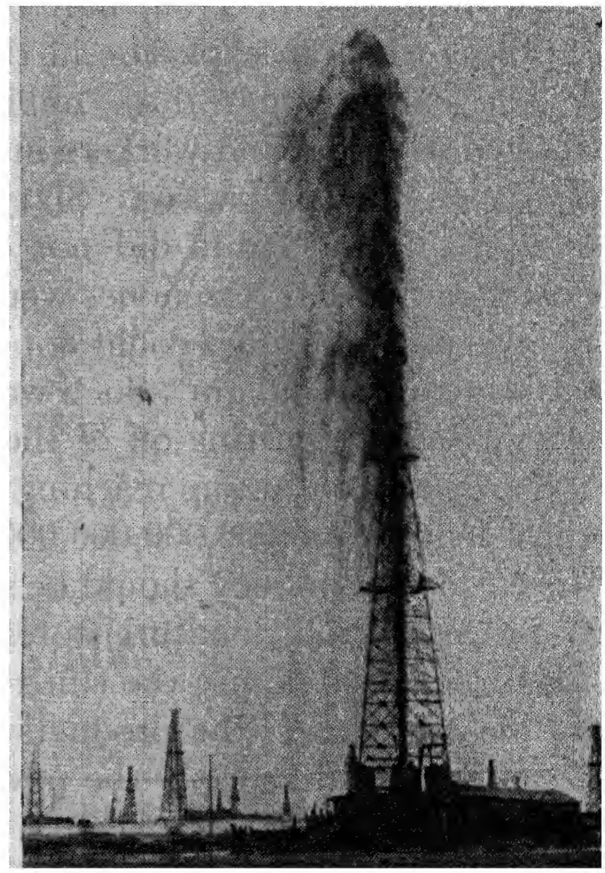


FIG. 100. A "gusher." A geyser of oil that is very difficult to control. (Courtesy of the Union Oil Company.)

More Power at Less Cost Should Be an Immediate Goal.

There are about 4,000,000 farms without electricity in the United States, partly because rural electrification is so expensive that private electric companies cannot afford to install the required equipment and partly because farmers' incomes are so small. The United States Government set up the Rural Electrification Administration in 1935 to aid in the building of rural power lines, and the Electric Home and Farm Authority to help farmers buy electric equipment.

Many more millions of city families cannot afford to buy electrical appliances that they need. One of the outstanding problems of today is cheaper electricity and less expensive electrical appliances. One of the major contributions of the Roosevelt Administration was the creation of the tremendous Tennessee Valley Authority, which had for one of its avowed purposes the reduction of electricity rates. Six million people are expected to benefit from this cheaper power.

Because electricity is a public utility, nearly all states have set up Public Service Commissions to regulate electric rates. Most of the electric industry in America is controlled by ten or more large holding companies, which had not been regulated until Congress passed the Public Utility Act of 1935. Many municipalities have built and operated their own power plants and have brought electricity prices down by demonstrating that electricity could be sold more cheaply than private companies were selling it.

Research Should Be Carried Out to Learn How to Harness Other Sources of Energy.

When we think of a future completely mechanized we must also think of inexhaustible sources of power to go with it. The finest machine in the world will not operate without power.

On January 16, 1936, half of New York City was thrown into darkness when an explosion in the Hell Gate plant cut off the power. In the early winter dusk millions of lights went out. Elevators stopped running, and workers in skyscrapers had to walk down many flights of dark stairways. Sixty thousand people were stranded in subways, traffic lights did not operate, motion-picture houses were closed, radios and telephones were silent. Refrigerators, stoves, irons, and washing machines could not operate, and surgical operations were performed by flashlight. Such was a sample of the disaster that would accompany the cutting-off of the electric power in our modern cities.

The energy of the sun reaching the earth each year is estimated to be equivalent to 400,000,000,000,000,000,000 tons of anthracite coal. More time and money should be spent in the study of photo-synthesis, the process by which nature stores the sun's energy. Chemical methods should be found to use the sun's energy to produce fuels from carbon dioxide and water, the products of combustion. Thirty-five minutes of sunlight would supply the power requirement of the United States for a year.

Previous to 1939, the probability of releasing atomic power seemed fantastic; but the splitting of uranium in 1939 with the release of relatively large amounts of energy indicated that atomic power is a problem on which much time and money might be spent with profit.

Dr. William D. Coolidge, director of research laboratories of the General Electric Company, states:

> It has been shown that in the case of the element uranium an enormous amount of intra-atomic energy may be set free, so much, in fact, that if further research shows how the process once started may be made self-propagating, we may be able to get as much energy from a pound of uranium as from millions of pounds of coal. This might prove to be a cheaper source of power than any other. Even if it were more expensive it might be revolutionary in those applications where weight and bulk are all important. It also seems possible that further nuclear research may show how the interatomic energy of some of the more common elements may be economically set free.

Dr. Lee de Forest, famous engineer, whose inventions have been so important in radio, motion pictures, etc., states:

> The cyclotron as developed by Prof. E. O. Lawrence, of the University of California, has already justified man's hope that eventually he will be able to

derive by elemental fission cheap, universally obtainable power in unlimited quantities. Our oil and coal resources must otherwise be exhausted within a few centuries. These must be conserved for more essential services than mere power supply.

In 1940 the Rockefeller Foundation demonstrated its faith in the possibilities of atomic power by giving $1,150,000 toward a new 4900-ton cyclotron to be erected at Berkeley, California.

Wind power has been used in windmills and is now being used on farms to run generators which charge batteries and thus provide a fairly constant source of power. Large-scale harnessing of the wind, however, depends upon storing the wind's energy. So far, all storage devices have been too expensive to be economically feasible.

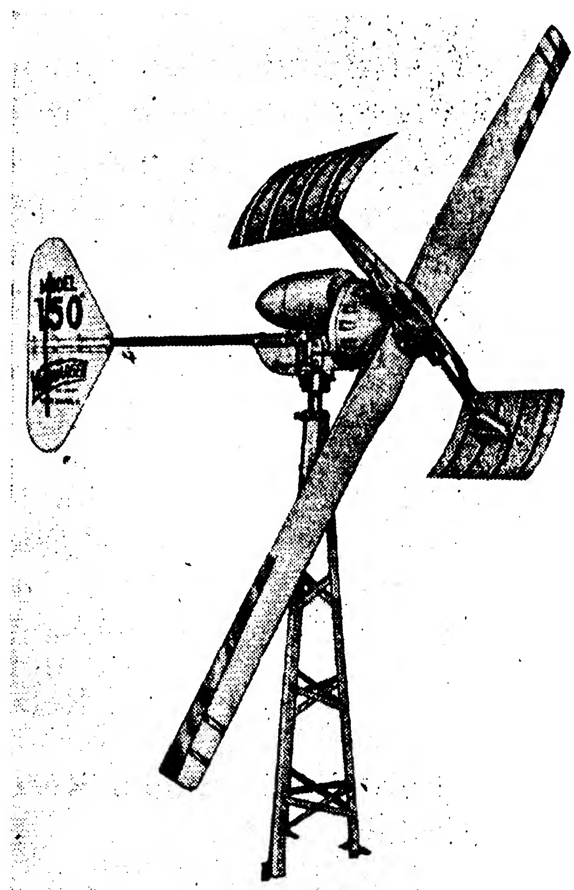


FIG. 101. A wind-driven electric generator. This generator starts charging in a 7½ mile wind. In good wind areas it will generate sufficient electricity to light the home, run the radio, vacuum cleaners, fans, washing machines, irons, and refrigerators. (Courtesy of the Wincharger Corporation.)

National Planning Has Been Made Necessary by Science and Is Dependent upon Science.

Where the ancients knew only soil, forest, wild animals, and a few simple metals, we know thousands of natural and artificial substances that we turn to our purposes. Where they worked slowly with arrow, axe, and plow, we operate with tractor and steam shovel, with poison and fire, with gold-dredge and dynamite. The low-powered civilizations of the past, rattling around in an almost uninhabited wilderness, could get along with low-powered plans. If their resources failed, they could move to new land. It is not so easy now. We depend for our lives on a vast, intricate network of technological processes, carried out in mine, farm, and factory. We cannot easily pack everything on a mule and trek. Therefore we have to manage what we have, finding ways to control the process of social change, or at least to see it coming and get out from under the wheels.

The simple political and industrial planning of the first years of the Republic, when Alexander Hamilton introduced the protective tariff, will not suffice to meet modern problems. At the present time the country is obliged to make decisions as to great systems of public works, as to elaborate public health services, as to the powers and relationships of corporations, and as to the

control and utilization of natural resources. These and many other problems have been accentuated by modern technological development, which has changed the jobs of working people, has opened up vast material resources, has speeded travel and communication, and has led to nationwide business organizations handling goods and services that were unknown to our ancestors. Science has created a new world, and only with an understanding of science is there any hope of establishing laws and customs for this new world that will work and give satisfactory results.[1]

The United States Government National Resources Planning Board[2] Committee "is concerned with the kind of planning which is a peculiarly American custom, based on an enthusiastic belief in the ability of a democracy to utilize intelligence."

You are urged to read the following reports published by the National Resources Committee. They may be obtained from the Superintendent of Documents, Washington, D. C., for ten cents each.

Planning Our Resources
Our Cities
Population Problems
Regional Planning
The States and Planning
Technology and Planning
Water Planning
Federal Relations to Research

Scientific Research Should Receive Even More Support than It Does Today.

Scientific research in industry in the United States was almost unknown in 1900. Today several thousand research laboratories are maintained by industries, some of which have expenditures ranging from five to forty million dollars a year. It is coming to be recognized that the price of progress in industry is research and that from 2 to 4 per cent of the income should be allotted to research. Some of the great research laboratories of today are those maintained by the Bell Telephone Company, the General Motors Company, the Eastman Kodak Company, the E. I. du Pont de Nemours Company, the Dow Chemical Company, the National Carbide and Carbon Chemicals Corporation, the General Electric Company, the Goodyear Tire and Rubber Company, the B. F. Goodrich Company, and the Hercules Powder Company.

The Mellon Institute, founded at the University of Pittsburgh in 1911 and built and endowed by Andrew and Richard Mellon, through

[1] From *Technology and Planning*, National Resources Committee, 1937.

[2] Formerly "The National Resources Board" and "The National Resources Committee."

a system of industrial fellowships supported by over 3500 companies at one time or another has been a very effective industrial-research agency.

Commercial research laboratories, such as the Arthur D. Little Company in Boston and the Twining Laboratories in Fresno, California, are well equipped to help industries with their problems.

One of the significant trends is the definitely democratic practice of small business firms organizing to maintain centralized research laboratories; the cleaners and dyers, the bakers, the medical profession, the dentists, and the canners are typical coöperative associations that maintain research laboratories. Consumer coöperative organizations are providing a much needed research service for consumers.

There are 122 private foundations such as the Brookings Institute and the Rockefeller Institute for Medical Research, which spend nearly $5,000,000 annually in research.

Research is recognized as one of the major functions of institutions of higher learning such as the State universities, the Massachusetts Institute of Technology, and the California Institute of Technology, many of which have annual research budgets of over one million dollars.

The Federal Government conducts research on problems dealing with the improvement of agriculture, the conservation of natural resources, mining, and the maintenance of physical standards. In all of these researches the government serves the double purpose of directing its own operations and supplying the people with important information. The Smithsonian Institution is an important semi-public research agency.

The United States Department of Agriculture maintains important research laboratories in the Weather Bureau, the Bureau of Animal Industry, the Bureau of Dairy Industry, the Bureau of Plant Industry, the Forest Service, the Bureau of Chemistry and Soils, the Bureau of Entomology, the Bureau of Biological Survey, the Bureau of Public Roads, the Bureau of Agricultural Economics, the Bureau of Home Economics, the Plant Quarantine and Control Administration, the Grain Futures Administration, the Food, Drug, and Insecticide Administration, and many agricultural experiment stations.

The Department of Commerce sponsors the Bureau of Standards and the National Advisory Committee for Aeronautics; the Department of the Interior operates the Bureau of Mines, while the Public Health Service also conducts important research activities.

The Federal Government spends for research about one dollar annually for every person in the United States, through about one hundred agencies in addition to those mentioned above.

The wide variety of research organization makes adequate provision for individual initiative. On the other hand, many important, pressing problems could be solved more quickly through the planning and coördination of research programs. It seems probable that the Federal Government will be the best agency for conducting practical researches on pressing problems, thus leaving to other research agencies the development of fundamental research. The present trend toward the use of intelligence in guiding Federal activities, national planning, and researches dealing with problems for the welfare of the public should be encouraged by every citizen.

STUDY QUESTIONS

1. Discuss the organizations which conduct research in the United States.
2. What departments of the United States Government carry on research?
3. To what ends are the majority of the United States Government researches carried out?
4. Why do colleges and universities not accomplish more in research than they do?
5. List the outstanding industrial research laboratories in the United States.
6. Discuss modern research in relation to the consumer.
7. Would you say that the research facilities of today are adequate?
8. How would you recommend that research be fostered?
9. What type of research should be conducted by the Federal Government and why?
10. What problems does the conservation of our energy resources involve?
11. Discuss the origin and functions of the National Resources Planning Board Committee.
12. To what extent can water power replace other energy sources?
13. What are some of the possible future sources of energy?
14. Why should conservation be undertaken in this time when an abundance of readily accessible energy sources are still available?
15. Discuss some of the Federal Activities which have been undertaken to conserve our energy resources.
16. Why is national planning necessary?
17. Discuss the water-power projects that have been sponsored by the National Government during the past decade.
18. In what respects are our power sources now inadequate?
19. Why is national planning now more urgent than it was one hundred years ago?
20. In what respects is national planning dependent upon Science?

UNIT V

SECTION 3[1]

MODERN MACHINES HAVE RAISED LIVING-STANDARDS

> To concentrate thought and effort upon dividing existing things rather than on the creation of new ones is a sure sign of degeneracy. It is the doctrine of one who would take from others rather than create for himself. — Henry M. Dawes.

Introduction.

Machines have made the United States the richest country in the world. They have made it possible for more people to have abundance and leisure. They have also brought serious social problems, many of which our government is struggling to solve. It is important that these problems be understood, because the most intelligent planning by our government will not solve these problems without our whole-hearted coöperation.

Modern Machines Are Combinations of a Few Simple Principles.

Leonardo da Vinci, the greatest inventor of history and also a great artist, invented the centrifugal pump, the dredge, the roller bearing, the universal joint, the conical screw, the rope and belt drive, link chains, bevel gears, and spiral gears.

The use of gears is an illustration of the way in which man magnifies the force he is able to exert in order to do work more advantageously. The rate at which work is done is power. In order to accomplish a given amount of work, less power is required if the work is done more slowly; that is, if the distance an object is moved during a given time is decreased. The use of the inclined plane is one method of decreasing the vertical distance an object is moved per unit of time. Thus it requires more power but less time to climb a steep stairway than one that is not so steep. The

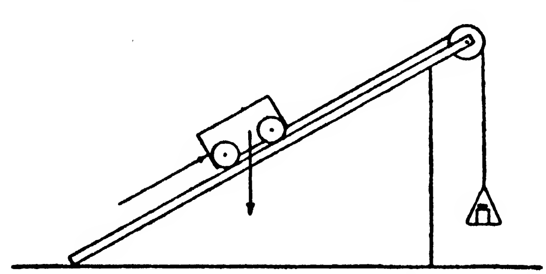


FIG. 102. The inclined plane.

[1] Much of the material in this Section was taken from the following publications of the Machinery and Allied Products Institute, with their permission:

More Facts on Technology and Employment
Machinery and the American Standard of Living

screw or jack is an example of a special type of inclined plane; thus a screw is forced into wood slowly with little power, while a nail is forced into it quickly with more power. A jack may be used to raise a heavy automobile because it enables a man to do a given piece of work by exerting his limited effort over a shorter distance in a given time.

A wedge is a double inclined plane that enables man to increase his force by decreasing the distance through which a force acts in a given time.

"Give me a place to stand and rest my lever on and I can move the earth," said Archimedes. This great mathematician and inventor was the first man to set forth the principle of levers, which he applied in constructing machines of warfare.

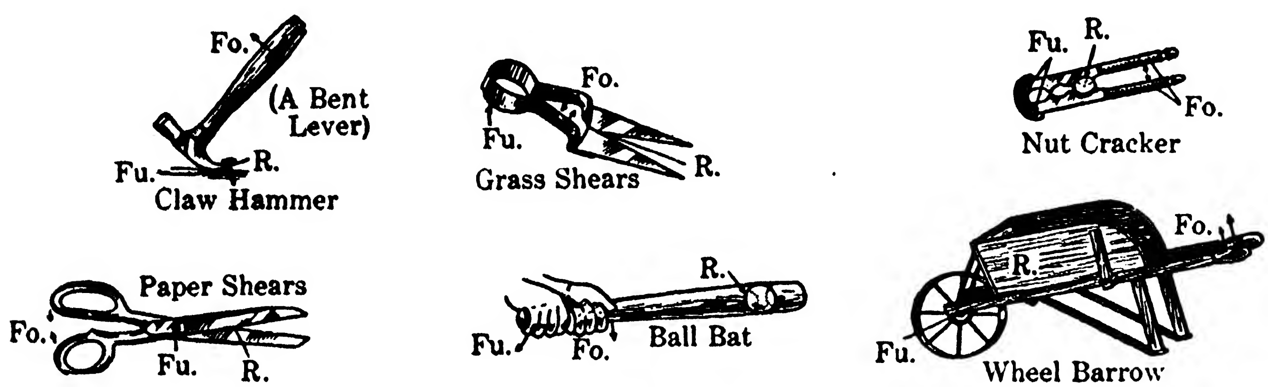


FIG. 103. To which class does each of these everyday levers belong? (From Pieper and Beauchamp's *Everyday Problems in Science*, published by Scott, Foresman and Company.)

Every lever must have a bar and a pivot called the fulcrum. Some common examples of levers are typewriter keys, automobile brake pedals and clutches, piano keys, scissors, teeter-totters, arms, and legs. Levers are classified as to the relative positions of the fulcrum, the effort (force), and the resistances, as shown in Fig. 103.

The lever aids man in doing work, for it enables him to exert a great force to move an object a short distance by doing an equal amount of work in which his limited force is made to act through a long distance. In addition to these three simple levers there are circular levers — wheels, axles, and pulleys.

The ordinary cart wheel is merely a device to lessen friction and is not classed as a machine. The wheel and axle, and pulley, on the other hand, are used to transmit and modify force and motion. Thus the motion of a slowly moving large wheel of a powerful engine may be distributed by belts, pulleys, wheels, cranks, and gears to a large number of rapidly moving parts.

All of the marvelous machines of today are examples of various combinations of these six simple machines — the lever, the wheel and

axle, the pulley, the inclined plane, the screw, and the wedge. These machines, in turn, are simply devices to give the advantage of increased speed, distance, or force.

The Invention of the Steam Engine Brought About the Industrial Revolution.

The invention of the steam engine, like many other important inventions, represented the bringing together of a number of different observations and simple devices; no one can be given credit for discovering the principle of the steam engine. *Hero* (between 100 B.C. and 200 A.D.) is credited with inventing the earliest steam engine, in which the recoil of steam issuing from a jet was used to make an arm carrying the jet move about an axis.

Up to the eighteenth century the chief hindrance to industrial development was the lack of power. Men, women, and children did back-breaking work from twelve to eighteen hours per day, animals were likewise overworked, and yet the results were comparable to what one would accomplish by attempting to cut a square mile of wheat with a hand sickle. Many mines used as many as five hundred horses to get the water out of the workings and were often abandoned after losing the battle with subterranean water.

It is true that windmills and water wheels had been put to work in the service of man, but no way had been discovered to transport the energy thus made available to industrial centers.

Guericke had demonstrated in the seventeenth century that a piston would be forced into a cylinder by the pressure of the atmosphere when a partial vacuum was produced between the piston and the bottom of the cylinder. The Dutch physicist, *Huygens*, tried exploding gunpowder in the bottom of the cylinder to force the air out through a valve in the piston, but this explosion engine was not efficient, and it was dangerous to use.

Denis Papin, who was engaged by Huygens to work on this explosion engine, proposed to produce the vacuum by the condensation of steam. Papin heated water in the cylinder to generate steam and then cooled the cylinder to condense the steam. Obviously, this alternate heating and cooling process was not very practical. In 1712, the year in which Papin died, *Thomas Newcomen* invented a steam engine in which he separated the steam boiler and the piston. The machine made four strokes a minute, but the addition of a jet of water inside of the cylinder to cool it increased the speed to twelve strokes a minute.

James Watt, a mechanic at the University of Glasgow, was one day given the job of putting in order a small model of a Newcomen engine.

He was impressed with the very large amount of steam required to operate it. Greater efficiency required that the cylinder be kept as hot as the steam, and yet the cylinder must be cooled as much as possible to obtain a good vacuum. While taking a walk by himself one Sunday, the solution suddenly occurred to him. He rushed to his workshop and constructed a steam engine with the condenser separate from the cylinder. The piston was forced up by introducing air into the cylinder and was forced down again by removing the air by pumping the air out of the cylinder by means of the steam-condenser. After ten years of work on the development of his steam engine, James Watt said, "To-day, I entered the thirty-fifth year of my life, and I think I have hardly yet done thirty-five pence worth of good in the world; but I cannot help it." Finally Watt found a wealthy backer, *Matthew Boulton;* but manufacturing difficulties seemed to be almost insurmountable. There were no machine-builders and tools. Finally, the great iron-founder *Wilkinson* created a sensation by producing a cylinder that was accurate to a quarter of an inch.

Watt's steam engine became a commercial success only after it was applied to pump water from the deep coal mines of Cornwall.

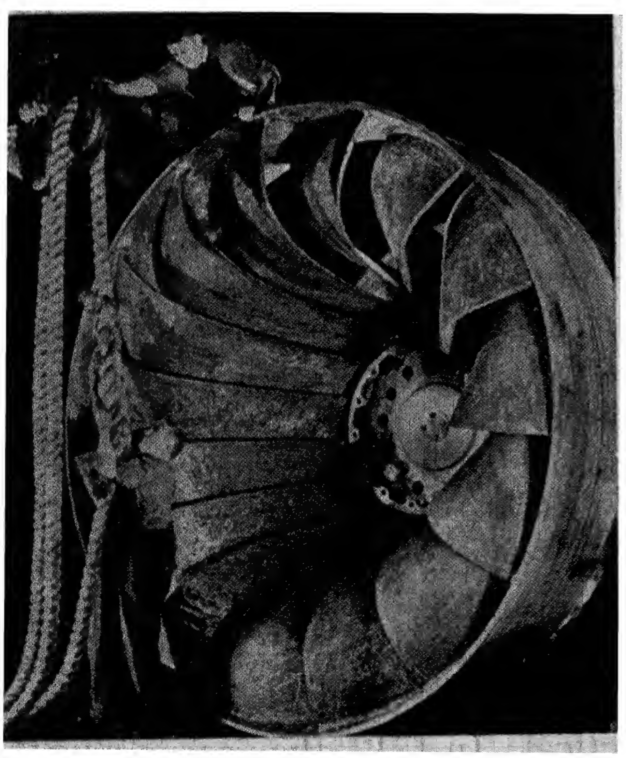


FIG. 104. Francis runner for a hydraulic turbine. (Courtesy of the Allis-Chalmers Manufacturing Company.)

The next advance in steam engines was to use the expansive force of the steam on one side of the piston and the partial vacuum produced by the steam in the condenser, on the other side of the piston. By thus avoiding the back pressure of the atmosphere, more power is developed. In reciprocating steam engines the steam acts alternately on either side of the piston. In some expansion engines the steam is allowed to expand into a second, third, or fourth cylinder, each larger than the preceding. The piston is fastened by means of a connecting-rod to a wheel or shaft, which is thus caused to rotate as the piston moves back and forth in the cylinder. Attached to the wheel or shaft is an eccentric, which cuts off the steam at the proper time. The large flywheel gives enough inertia to the system to maintain a uniform motion when steam is not pushing on the piston.

In 1884 *Charles A. Parsons* invented a more efficient steam engine, the steam turbine. Steam turbines are used in ocean liners and power stations today. In one type of steam turbine the steam pushes curved blades around on a number of wheels on the same shaft. The steam strikes a row of blades on a wheel, then a row of stationary blades to change its direction, and then a row of blades on a wheel again, until the energy of the steam is about exhausted.

Rotary Motion Has Many Advantages over Reciprocating Motion.

In the reciprocating steam engine the piston moves back and forth, coming to a dead stop between each change in direction of motion, thus wasting energy and cutting down speed. The power-driven circular saw saws wood much more rapidly than the ordinary reciprocating handsaw of the carpenters. Similarly, the steam turbine is more efficient and more speedy than the reciprocating steam engine. Vibrations are cut down in rotary machines. For that reason a steam turbine is sometimes preferred to a Diesel engine, which is a reciprocating engine, for use in ocean liners. Rotary machines are much easier to lubricate than are reciprocating engines; compare the ease of lubricating an electric motor with the problem of lubricating an internal-combustion engine.

Many inventions have represented rotary machines which would replace reciprocating machines. Thus the oar was replaced by the propeller, the paddle by the paddle wheel, the broom by the carpet sweeper, the carpenter's plane by the rotary plane, the sickle or scythe by the lawn mower, and the file by the grinding wheel.

Technological Advancement Has Not Been Responsible for Unemployment.

The 1930 census shows there were 811,000 stenographers and typists as compared with 615,000 ten years earlier. In the same period, bookkeepers, cashiers, and accountants increased from 735,000 to 931,000. During this same period the manufacture of typewriters, cash registers, adding and calculating machines, and numerous other business machines increased.

Dial telephones increased from 27 per cent in 1921 to about 32 per cent in 1930 in the Bell system; and yet telephone operators increased from 190,000 in 1920 to 249,000 in 1930, and the number of telegraph and telephone linemen almost doubled.

Railroad employment dropped by about 1,000,000 workers since 1920, but in 1935 there were 2,700,000 truck drivers, 153,000 bus drivers, and 301,000 highway workers.

The Demand for Workers Is Higher in Mechanized Industries than in Hand Trades.

Marked mechanical developments have taken place in the manufacture of women's clothing, and yet employment increased 121 per cent from 1925 to 1936. The majority of unemployment during the depression was in the building industries, where machines have made little impression. The total decrease in employment in all of the manufacturing industries during the depression was only 1,700,000.

Unemployment Is the Result of an Increased Supply of Workers Rather than a Decreased Number of Jobs. The Supply of Workers in Proportion to Population Increased 50 Per Cent in One Hundred Years.[1]

There are 15,000,000 more workers available today than would have been available from the same population a hundred years ago, because of the increasing concentration of the population in the older age groups. In 1900, 55.7 per cent of the population were twenty years of age or over, while 61.2 per cent in 1930 and 65.5 per cent in 1940 were twenty years of age or over. Smaller families and increased life-expectancy due to the advances of modern medicine have been largely responsible for this trend. Even during the depression there was a higher percentage of the population in jobs than in "boom" times of a century ago.

As a result, in part at least, of an increased supply of workers, the number of children working is constantly declining. In 1900 one child out of every five between the ages of ten and fifteen was employed. In 1930 the figure was less than one in twenty.

Present trends indicate that the supply of workers per thousand of population has about reached a peak.

Living-standards Have Been Improved by the Advance of Technology.

The present standard of living would be impossible without machinery. Workmen's wages have increased because machinery has made it possible for the workers to step up their output.

During the period 1899–1929, wages paid by manufacturers increased 479 per cent, while factory employment increased 88 per cent. During the same period manufacturers increased machinery 331 per cent.

Average weekly incomes of factory wage-earners in December, 1938,

[1] The consuming power of human beings is, for all practical purposes, unlimited. It follows, therefore, that the most strenuous efforts of every available worker could not produce an *absolute* surplus of commodities even though they used every labor-saving device ever invented. Where production is determined by need rather than profitability, there is no involuntary unemployment.

were 105 per cent higher than in 1914, although food, clothing, and shelter had increased only 40 per cent.

When the United States was using $23 worth of machinery per capita, Great Britain was using $10 worth and paying one third the American wage; Germany was using $9 worth and paying one fourth the American wage; China was using 5 cents worth of machinery per capita and paying one twentieth the American wage.

Technological advancement has not only furnished goods and services that would have been impossible without the machine, but it has also increased the capacity of many people to obtain these goods and services by increasing their incomes and decreasing the prices of the goods and services.

The United States has only 7 per cent of the world's population, but Americans operate 33 per cent of the world's railroads, own 50 per cent of the world's radios, use 60 per cent of the world's telephone and telegraph facilities, and drive 80 per cent of the world's automobiles.

The Work Week Has Declined.

Hours of Work per Week	Year
56.8	1899
51.5	1914
48.3	1929
34.4	1938

Had it not been for increased production made possible by technological advance, the reduction in the work week would have greatly lowered the American standard of living.

Increased Production Made Possible by Lower Prices Is Essential to Higher Living-standards.

Lower prices for goods and services will make it possible to buy more goods; thus production and employment will increase, and capital will not lose because volume reduces the overhead per unit. Lower prices can be made possible, however, only by research, which will point out how better products can be produced at less cost.[1]

Mass Production Lowers the Cost of Production.

A modern Ford car made without the use of mass production methods would cost $17,850.

Domestic refrigerators manufactured at the rate of 200,000 a year

[1] At the present time in capitalistic countries prices tend to be monopolistic prices rather than competitive prices. There is a point in the increase in production below which profits decrease. Under monopoly conditions output is restricted so as to give maximum profit.

cost $400 each, while, twelve years later, when 2,000,000 refrigerators were manufactured, the price was only $163.

In 1914 a 60-watt electric-light lamp cost 43 cents, while a greatly superior lamp cost only 10 cents in 1941.

Electric fans that cost $12.20 in 1914 could be replaced by superior fans at $2.75 in 1938.

The first electric clocks sold for $30; by the time 2,500,000 a year were being sold, the price dropped to $4.00.

One of the Most Significant Steps in Making Mass Production Possible Was the Development of Interchangeable Parts.

Eli Whitney, inventor of the cotton gin, was largely responsible for the evolution of the principle of interchangeable parts. In 1818 he

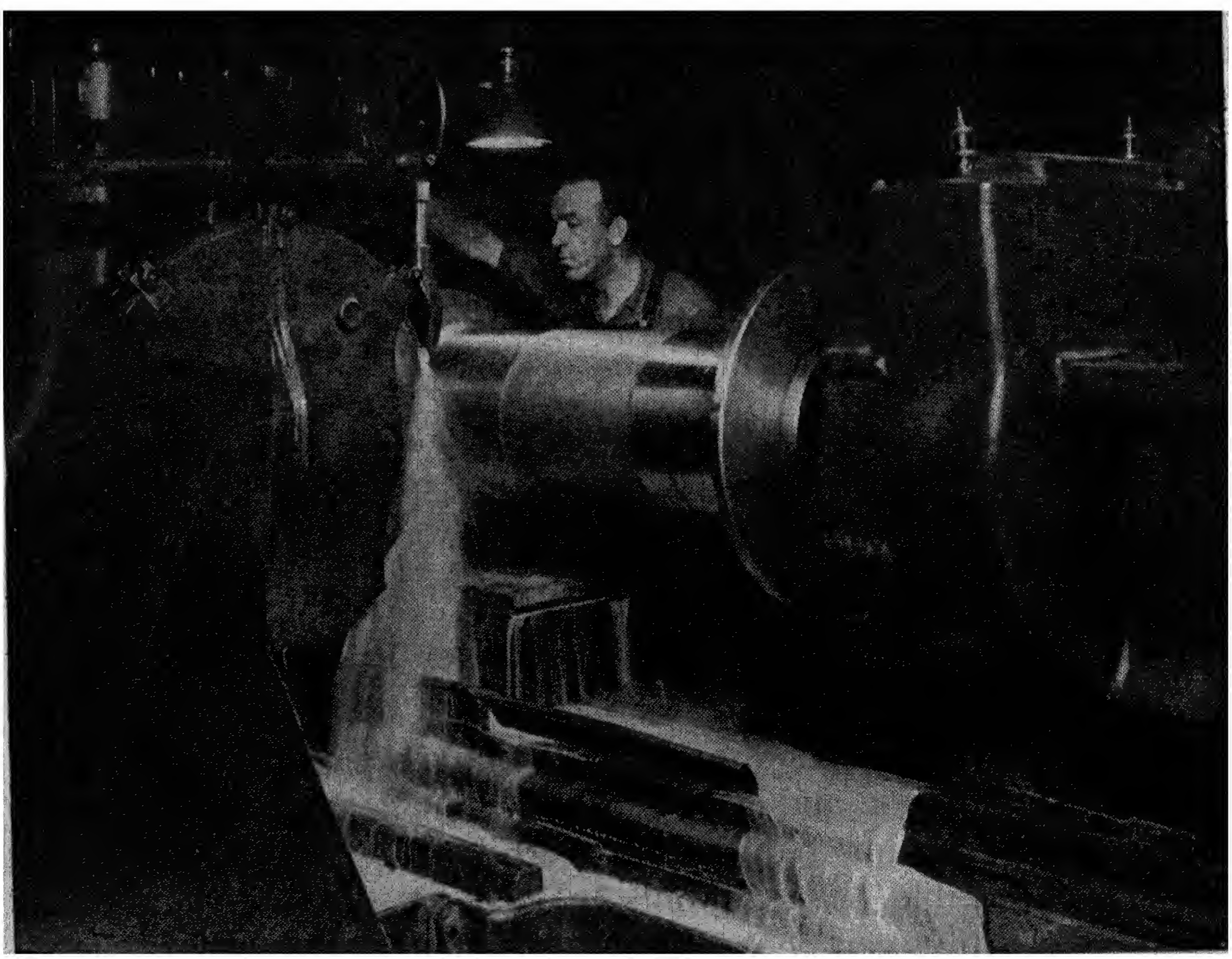


FIG. 105. Precision grinding one of the main parts of an electric locomotive. Both the part and the abrasive wheel, which is under the hood to the left, are rotated, the abrasive wheel at much higher speed. (Courtesy of the Westinghouse Electric and Manufacturing Company.)

instituted the production of interchangeable parts for firearms. America has made such progress in the development of interchangeable parts that this principle is known in Europe as the American system.

Industrial Accidents Have Declined.

As the result of the development of a vast number of safety devices and other improvements industrial accidents have been reduced 61 per cent in frequency and 61.3 per cent in disabling injuries.

Highly mechanized industries have the best safety records.

Machine Tools Have Played an Important Part in the Advance of Technology.

Watchmaker's precision, precision to a ten-thousandth of an inch, has been made possible by modern machine tools, which represent a major contribution of engineering, metallurgy, and invention to modern civilization. Machine tools are the reproductive members of the machine world. Machine tools are the machines that make machines.

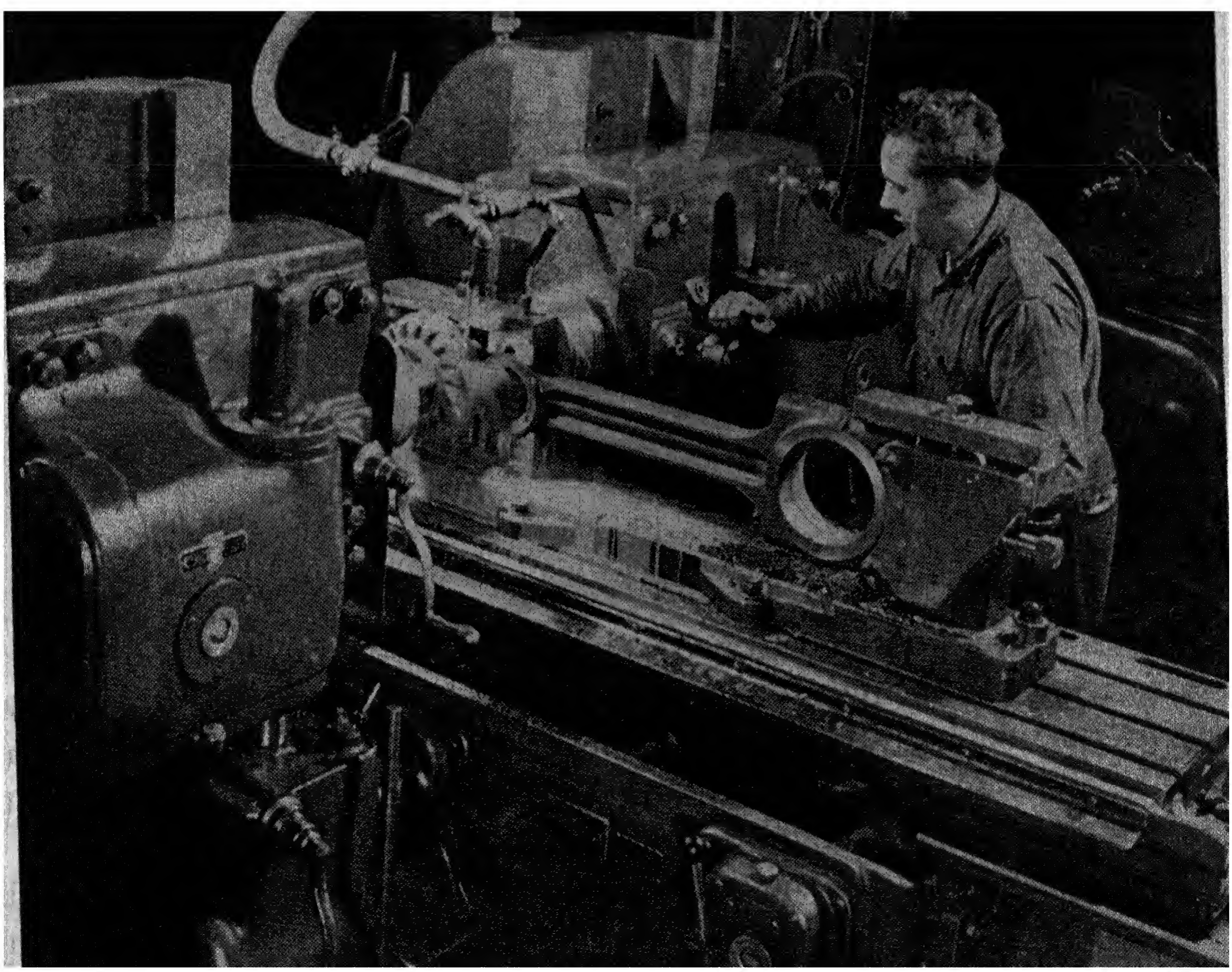


FIG. 100. A milling machine simultaneously finishing both sides of a large Diesel engine connecting rod. The two cutters have multiple teeth, similar to a circular saw. One of them is seen at the small end of the rod; the other is just behind it.

The connecting rod is passed back and forth between the cutters which are rotated at high speed and moved closer and closer together with each pass until the rod is reduced to the desired thickness. (Courtesy of the National Machine Tool Builders' Association.)

Milling machines which remove metal by means of rotating cutters, planing machines which remove metal by moving an object backward and forward under a stationary cutting-tool, turning machines which remove metal by applying a cutting-tool to an object while in rotation, grinding machines, and power drills are the parents of printing presses, tanks, automobiles, and airplanes.

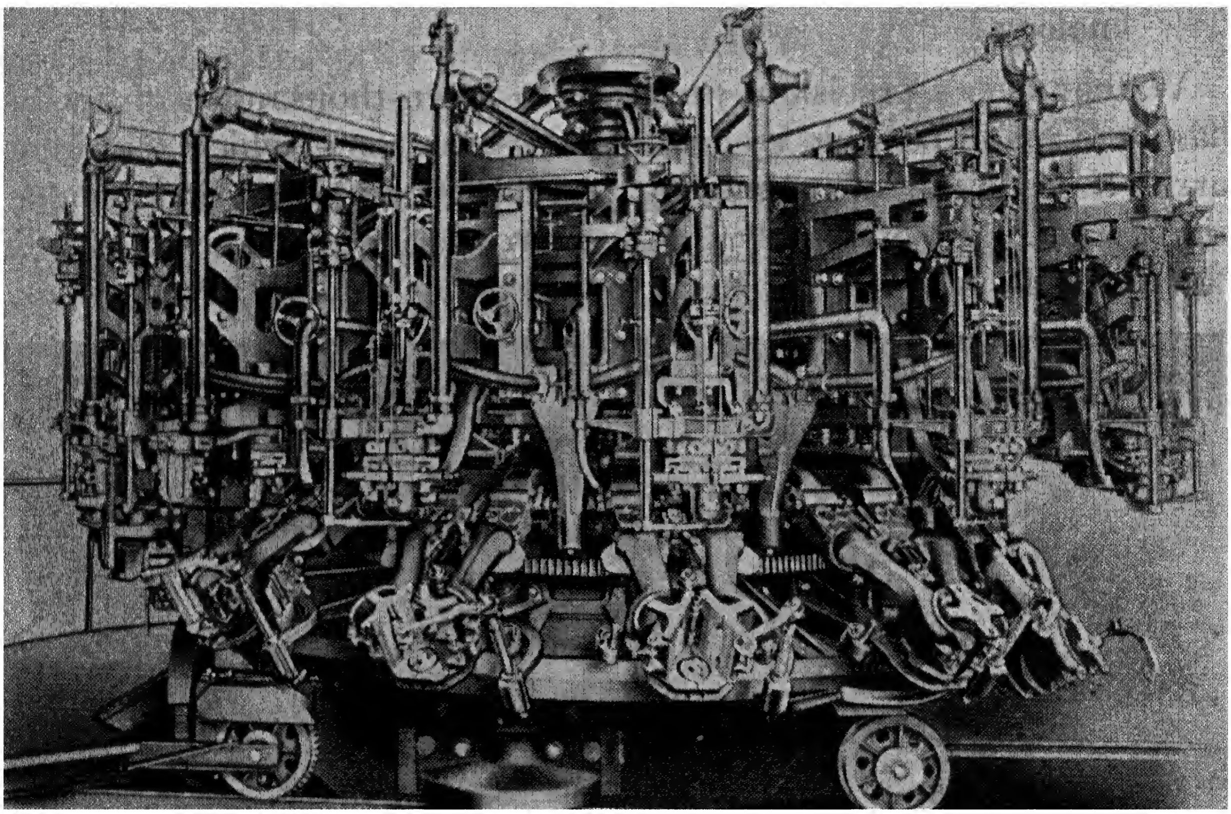


FIG. 107. Idealistic view of a 15-arm Owens bottle blowing machine. (Courtesy of the Owens-Illinois Glass Company.)

The machine-tool industry resembles research in that it employs relatively few, but highly trained, men. The total number of employees in the machine-tool industry in the United States in 1940 was 83,000. The machine tool makes possible mass production, but it, like research, cannot be produced by mass-production methods.

The improvement in the design and materials used in machine tools renders older tools obsolete in about seven years. One of the problems of modern industry is that of retooling every few years. The introduction of new tools generally involves changes in factory buildings, rerouting materials in assembly lines, changes in methods of handling, etc., to such an extent that retooling is not economically feasible until the older tools have paid for themselves. Progress in production methods is therefore closely geared to the useful life of machine tools. A single machine tool may cost as much as $150,000, and for that reason it cannot be replaced very often.

Automatic Machines Are Gradually Replacing Semi-automatic Machines.

Most of the machines in present-day factories require people to tend them. Machine-tenders have to do the same thing day after day, at the pace which the machine sets. Such work is not creative, and such

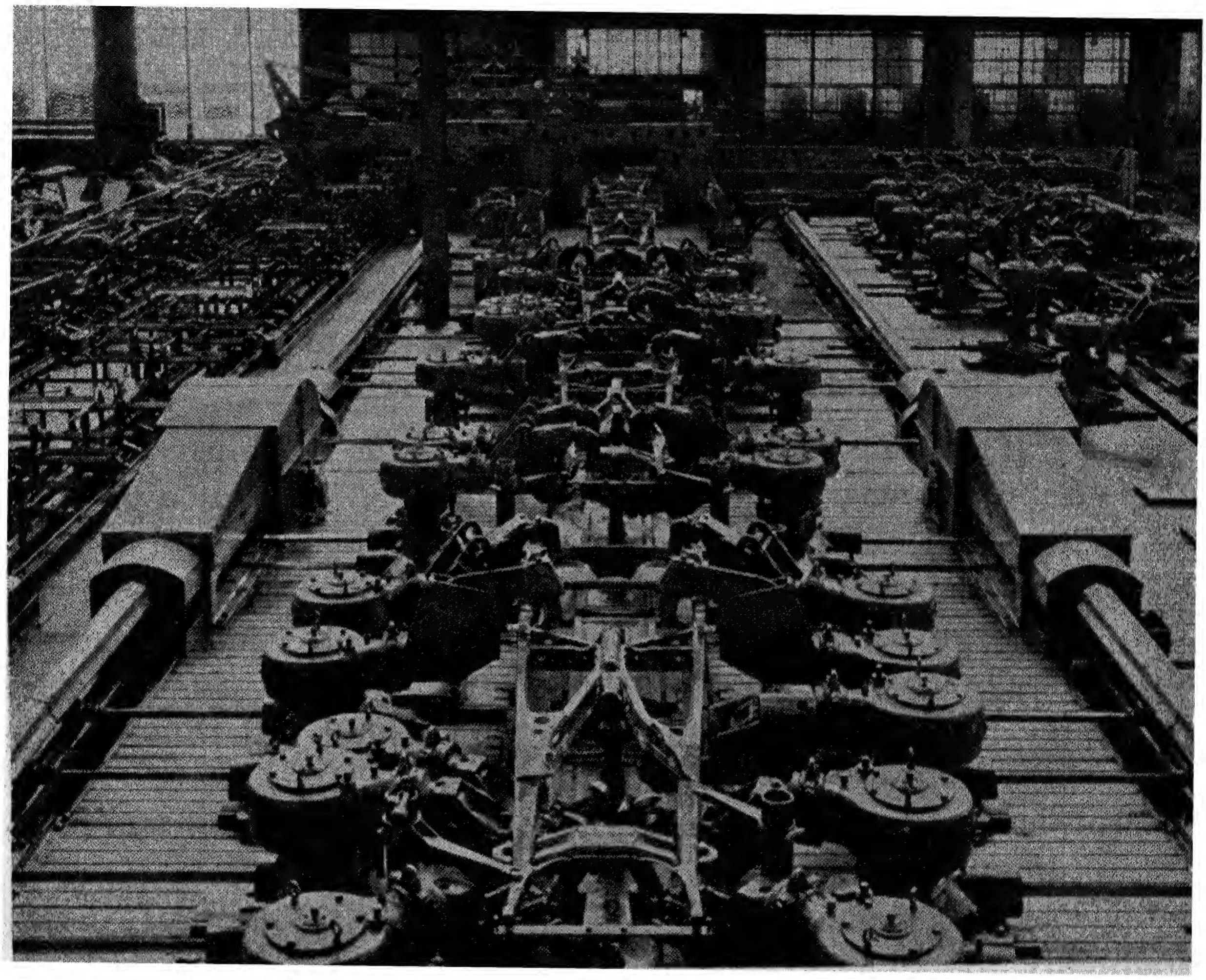


FIG. 108. Automatic automobile frame plant. Capacity of automatic plant, 8000 finished and painted frames per day. (Courtesy of the A. O. Smith Corporation.)

workers are really slaves to the machines which they tend. An important development in industry is the introduction of automatic machines, which require no human labor other than that involved in producing, adjusting, and repairing them. Modern nail-making machines keep up their incessant clatter without the presence of an attendant. Modern automatic bottle machines can turn out 250,000 bottles a day. Modern automatic die-casting machines can turn out castings at the rate of 4,204,800 per machine per year. Automatic punch presses help to make Woolworth stores possible.

Electrical devices, to be studied later, such as solenoids, thermostats, meters, magnetic valves, transformers, electromagnets, vacuum tubes, and the electric eye have made possible automatic machines that could

not otherwise be produced. Machine-tending instruments have taken over the jobs that have to do with weighing, sorting, inspecting, counting, temperature-reading, and even chemical analysis of exhaust gases and raw materials. A modern laundry machine washes the clothes, rinses them three times, and spins them dry enough to hang on the line, using the proper length of time and the proper water temperature for each operation. The only thing that the housewife has to do is to put the clothes and the proper detergent and water-softener in the machine and operate the starting-switch.

The A. O. Smith Company of Milwaukee employs 600 engineers, but only 200 skilled workmen, in its plant, which uses automatic machines to turn out 10,000 automobile frames every 24 hours.

Adult Education Will Be Required to Help Society to Adjust Smoothly to Changes Produced by the Machine.

A study of present trends points toward fewer machine tools, the workers being arranged in shifts and the machines being used day and night. Cheaper electricity will facilitate night-shift work, and twenty-four hour a day operation of machines will promote more rapid changes in industrial processes because fewer machine tools will be required and therefore less money will be tied up in the machines. Furthermore the machine tools will wear out more quickly and will thus require replacement with more modern machine tools.

Present developments also point toward a very much more extensive use of automatic machines.

It must be recognized that while new scientific discoveries will undoubtedly absorb more workers than are displaced by the increased use of automatic machines, yet many people who are displaced by machines will find it difficult to find new jobs because their training and experience have been centered on the kind of work for which the demand is decreasing. During the past decade many streetcar conductors and motormen have been thrown out of employment, and it is difficult for a man between fifty and sixty-five years of age, who has done nothing but run streetcars for twenty-five or thirty years to adjust himself to a new job.

One of the adjustments of society to this problem of the displacement of workers by machines is the widespread development of adult education. Unemployment insurance will help to provide a living while the worker is preparing for a new job. The majority of adults did not receive as much higher education as the younger generation is now enjoying, and as a rule their education was less practical and less general than that which their children are receiving. The scientific

knowledge now being taught in the schools was not known when many present adults went to school, and the scientific attitude and method had not been generally recognized as an essential for every citizen in a democracy. Many adults will find that, when they are displaced from their jobs, they will have to compete with very much better-prepared younger people for new jobs. Furthermore, scientific developments

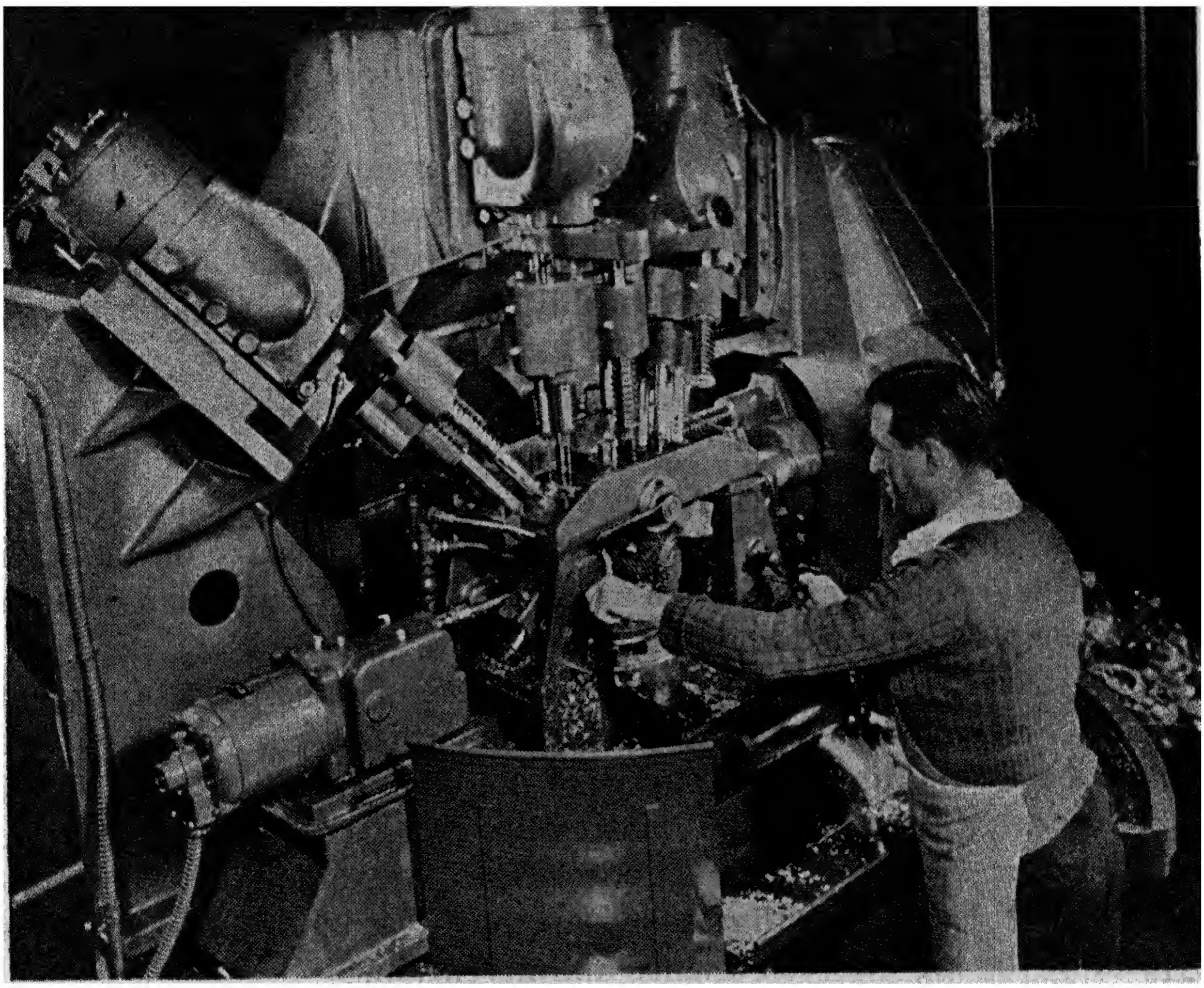


FIG. 109. New machine tool at Pratt and Whitney Division, United Aircraft Corporation, East Hartford, Connecticut. This machine drills 14 holes simultaneously in aircraft engine cylinders. Drills come in from five different directions. The operation is entirely automatic. This machine and two similar ones for reaming, countersinking, spotfacing and tapping, now do in three minutes what previously required work on seven machines and took one hour. (Courtesy of the National Machine Tool Builders' Association.)

and the progress of technology are taking place at an ever accelerating pace, which means that our young people who are now graduating from the people's colleges will find themselves to be so far behind the times within twenty years, unless they make it their business to continue their education after their formal schooling, that they will be ill fitted for employment in the new industries that do not now exist and poorly equipped to cope with the new social problems that will arise.

The National Resources Committee in its report on *Technology and Planning* states that "Education is an essential service of intelligence, in which children and *adults* are informed of the facts and taught to think of the alternative courses open to them."

The time has arrived when every young person and every adult must realize that education is a process that is never completed and that a formal education is but the introduction and preparation for a lifelong pursuit of knowledge and all-around development. Adult education will, therefore, be emphasized more and more during the next few years.

One of the fundamental purposes of *Man's Physical Universe* is to enable students to obtain a sufficient background in the field of the physical sciences to enable them to keep up with the developments of Science and technology by reading such weekly publications as the *Science News Letter* or such monthly publications as the *Scientific American* and the *Science Digest.*

Inventions Are Predictable.

In October, 1920, the *Scientific American* predicted a long list of inventions that would occur during the next twenty years, on the basis of scientific developments known in 1920. By 1940, 78 per cent of these inventions had been made.

The reason why inventions can be predicted on the basis of present scientific developments is that it takes time to apply knowledge. The basic ideas of picture telegraphy were not commercially applied until 88 years after their discovery; it required 70 years for the airplane development and 40 years for sound pictures to attain industrial significance. The long time that television was "around the corner" is typical of the lag between science and invention.

The fact that inventions can be predicted and that there is a definite lag between an invention and its commercial application makes it possible to anticipate the effects of technological advances on society and to plan accordingly.

STUDY QUESTIONS

1. What simple machines are illustrated by the following: (*a*) bicycle, (*b*) can opener, (*c*) chisel, (*d*) playground slide, (*e*) automobile jack, (*f*) meat grinder, (*g*) knife, (*h*) automobile clutch, (*i*) scissors, (*j*) saw, (*k*) lawn mower, (*l*) windmill?
2. Why is it necessary to push or screw the handle of a jack so many times when jacking up a car to change a tire?
3. Why is it easier to kill a fly with a fly-swatter than with the hand?
4. Why does an axe split a log when driven into it?

5. Why does a bicycle have a large sprocket gear on the hanger and a small sprocket on the driving-wheel?
6. What is the purpose of the gears in an automobile?
7. What type of machine is the nut and bolt?
8. All of the marvelous machines of today are combinations of what six simple machines?
9. What is the function of a machine?
10. Give a brief outline of the history of the development of the steam engine.
11. What problem concerning the Newcomen steam engine bothered James Watt, and how did he solve this problem?
12. What difficulties hindered James Watt in the development of his steam engine?
13. What is a steam turbine? Why is it quieter than a reciprocating steam engine?
14. What advantages do rotary-motion machines possess as compared with reciprocating-motion machines.
15. Give several examples of reciprocating-motion machines that are being displaced by rotary-motion machines.
16. Why are rotary-motion machines more efficient than reciprocating-motion machines?
17. Suggest a possible cause of unemployment.
18. Prove that mechanization has not been an important factor in unemployment.
19. In what respects has mechanization raised the living-standards?
20. How do lower prices raise the living-standards?
21. How may the prices of consumers' goods be lowered?
22. What problems have been created by the machines? Which of these problems are receiving the attention of (*a*) cities, (*b*) states, (*c*) the United States Government?
23. What predictions can you make on the basis of the present developments in the airplane industry and in the use of automatic tools?
24. Why is it possible to predict inventions?
25. Why is it now possible to plan ahead so that few if any new technological developments will appear without warning to disorganize society?
26. Why will adult education be increasingly more important?

UNIT V

SECTION 4

POWER-DEVELOPING MACHINES REVOLUTIONIZED TRANSPORTATION

> Machines for navigating are possible without rowers, so that great ships suited to river or ocean, guided by one man, may be borne with greater speed than if they were full of men. Likewise cars may be made — so that without a draught animal they may be moved with inestimable speed . . . and flying machines are possible so that a man may sit in the middle turning some device by which artificial wings may beat the air in the manner of a flying bird. — Roger Bacon.

Introduction.

Modern transportation, like modern communication, is the product of the rapidly increasing application of scientific knowledge to the problems of everyday life.

The history of the development of transportation reveals many cases of opposition of existing transportation agencies to new types of transportation, followed by the inevitable development of these new types of transportation and the consequent wasteful competition which resulted in unfair practices. Competition often ended in consolidation, which permitted greater efficiency but also permitted monopolies to make unfair profits. This brought about the Interstate Commerce Act of 1887 to prevent discrimination. Finally, in 1914, Congress passed the Clayton Anti-Trust Act to promote competition.

The problems of transportation are typical of the problems introduced by the development of modern technology, and the methods by which a democracy solves these problems make a fascinating study. In general these problems must be solved in such a way as to eliminate waste and increase efficiency, thus raising the general standard of living but at the same time preserving individual initiative and encouraging new and better ways of doing things. The solution of these problems presents a challenge to every human being.

Transportation by Water Has Witnessed Great Changes.

The value of water transportation was realized many centuries ago. The Roman vessel, with its several banks of oars operated by slaves,

represented a mere increase in the size of boats operated by man power. In China today boats are towed up the rivers and through the vast network of canals by human beings. The building of canals in China hundreds of years ago and the more recent construction of the Suez Canal, the Panama Canal, and other canals greatly facilitated transportation by water.

The Phoenicians are often credited with the invention of the sailing vessel, which greatly aided exploration and the development of world commerce. For many centuries improvements in water transportation consisted merely in increasing the size and seaworthiness of sailing craft.

Though the sailing vessel is still used to some extent, it is too much subject to the vagaries of the weather and too slow to meet modern man's general needs.

In 1707 *Denis Papin* built the first steamboat and set out to cross the English Channel. At Munden, however, the watermen, fearful that such a contrivance would take away their livelihood, smashed the boat to pieces, and Papin barely escaped with his life. Other men produced steamboats with rather indifferent success during the next hundred years. In 1803 *Fulton* completed a steamboat in France; but, the very night before it was to be tried out, it broke into two pieces during a gale, for Fulton had not constructed a strong enough hull to house his machinery. In 1805 Fulton took his steam engine to America, a trip that required two months. On August 16, 1807, Fulton's *Clermont* made its memorable voyage up the Hudson from New York to Albany, a distance of 150 miles, in 32 hours. In 1838 the *Sirius*, a small ship of 703 tons, was the first steam vessel to cross the Atlantic Ocean entirely under her own power. She made the trip in 17 days, consuming all of her coal and even burning some of her spars. In 1839 another steamship, the *British Queen*, made the same trip in 14 days.

In 1829 the following letter was written:

> Dear Sir
>
> We are entirely unacquainted with the cost of a steamboat and would not like to embark on a business of which we are quite ignorant. Must, therefore, decline taking any part in the one you propose getting up. We remain, Yours, S. Cunard and Company.

By 1840, however, this company had changed its mind, and its large steamship, the *Britannia*, made the trip from London to Boston in 14 days. In 1862 this same company's steamship, the *Scotia*, its last paddle-wheel vessel, made the trip in 9 days. In 1867 its ship, the *Russia*, a screw ship, made the trip in 8 days and 24 minutes.

From that time to the present, progress in shipbuilding has been represented by an increase in size, speed, safety, and luxury. Tremendous rivalry between the steamship lines of the different nations has resulted in the production of huge vessels, which, although they are probably uneconomical, nevertheless represent the last word in the applications of scientific knowledge.

In 1938 the *Queen Mary* made the eastbound trip across the Atlantic Ocean in 3 days, 20 hours, and 42 minutes.

Railway Transportation Made Great Progress during the Past Century, but It Is Now Facing New Competition.[1]

Progress in transportation has always meant more speed, reliability, and convenience at less cost. Today one can take a two-hour train ride for the cost of a five-mile riksha trip in China. This progress has always been opposed by people and interests who fear the new competition. Canal and stagecoach companies opposed the development of railroads; and later the railroads, in turn, tried to oppose transportation by automobiles.

The earliest railroads used horse-drawn cars, the first steam locomotive being introduced in England in 1804. In 1830 the Baltimore and Ohio Railroad completed a 15-mile road from Baltimore to Ellicott's Mills and put horse-drawn cars into service. In 1831 the Mohawk and Hudson Railroad Company constructed a railroad from Albany to Schenectady and put the famous DeWitt Clinton steam locomotive into service.

In 1850, 9021 miles of railroad were in operation. The first railroad was completed to the Pacific coast in 1869, and by 1916 the total railroad mileage in the United States was 254,251 miles.

In railroad transportation, we see again the ever increasing application of scientific knowledge. Space does not permit an account of the evolution of the modern light-alloy train from the wooden and later the all-steel trains nor an account of many important inventions such as the air brake, automatic couplers, electric signals, and other safety devices.

The development of the electric railroads from street railroads into interurbans and the recent electrification of hundreds of miles of railroad lines cannot be discussed. Although many interurban and electric street railways have now been displaced by the new transportation agency, the automobile, electricity is superseding steam to some extent in large terminal areas, heavily used stretches of railroad, on mountain

[1] The value represented by the railroads in the United States is $26,000,000,000. In 1939 railway employees were paid $1,864,000,000 in salaries and wages.

grades, and in tunnels, where its lack of smoke and gases and fire hazard makes its use worth while.

The railroads have introduced quiet, well-lighted, comfortable, and even luxurious, air-conditioned trains. They have also increased the speed of both freight and passenger trains and decreased their rates. One of their great achievements has been that of increasing the safety of transportation. Railroads have greatly improved their freight service by operating fleets of trucks which make possible door-to-door service.

By 1940 there were 1200 mile-a-minute runs in the United States, while the speed of freight trains had increased 62 per cent since 1920.

In 1940 there were 11,715 air-conditioned passenger cars in operation.

With less than 6 per cent of the world's land area and with less than 6 per cent of the world's population, the continental United States has 31.2 per cent of the world's railroad mileage.

If all railway bridges in the United States were strung together, they would reach from San Diego, California, to St. Johns, Newfoundland.

The longest railway tunnel in the United States is the Cascade Tunnel, through the Cascade Mountains in Washington, 7.79 miles in length. Boring was started simultaneously from both ends, and when the construction forces met in the center they were only a fraction of a foot out of alignment — that *is* engineering.

The railroads created standard time in 1883, thus abolishing more than fifty different times in the United States; four standards, Eastern, Central, Mountain, and Pacific were adopted in their place.

The First Self-propelled Highway Vehicles Were Operated by Steam Engines.

In the period between 1828 and 1838, *Walter Hancock* built and operated six steam carriages in England that covered 4200 miles and carried 12,761 persons without accident or delay during a period of three months. Rural England was conservative, however, and the horse-drawn coach and toll-road interests combined in opposing newfangled vehicles. Even as late as 1865 an act was passed by Parliament which decreed that no power vehicle could be used on a highway unless it was preceded by a man on foot carrying a red flag. Even in France, where the public was favorable to self-propelled vehicles, the speed limit was four miles per hour in the country.

There was no opposition to the development of self-propelled vehicles in America, but the lack of good roads made them impractical. In 1871 *Dr. J. N. Carhart* built a steam buggy, but it was just one of a

series of crude attempts to fit engines into horse-drawn vehicles instead of designing vehicles to fit the engines. Later it took many years for the automobile to outgrow the horseless-carriage stage of its evolution.

In 1789 *Oliver Evans* (1755–1819) received the first United States patent for a "self-propelled" carriage.

Steam-propelled road vehicles were highly developed in France during the next hundred years and received special impetus with the invention of *Leon Serpollet's* "flash generator" in 1888–1889, which generated steam in a very short time and which was applied in the White and Stanley "steamers" in the United States.

The Internal-combustion Engine Has Gradually Replaced the Steam Engine.

The early developments in highway, railroad, and water transportation all used the steam engine; but the steam-propelled automobile has disappeared from the highway, and many boats and trains are now using the Diesel type of internal-combustion engine. The principle of the internal-combustion engine and its application to automobiles and airplanes will be discussed in the following sections of this Unit. The following brief history of the development of the internal-combustion engine will serve as an introduction to the following sections.

In 1860 *Lenoir* of Paris made a gas engine which used coal gas and was fired by a spark from an induction coil and electric battery. In 1862 Lenoir successfully applied this engine to a road vehicle, but he was handicapped by the fact that he could carry only a small amount of fuel.

In 1867 *Otto and Langen* of Germany were granted a United States patent for the first four-cycle compression engine. In 1885 *Daimler* adapted Otto's gas engine to the use of petrol.

In 1876 *George Brayton*, a Boston engineer, exhibited a petrol engine, which was inferior to Daimler's engine, however.

In the 1880's petroleum distillates were first used for internal-combustion engines.

In Germany, *Gottlieb*, *Daimler*, and *Carl Benz* competed in the production of improved gasoline-operated motor vehicles.

Levassor of France adapted Daimler's patents to the production of motor vehicles that introduced many of the features of modern automobiles. Levassor placed the engine in front, and it is still there today.

In 1892 *Charles E. Duryea* and his brother *Frank* built the first American gasoline car.

In 1899 the Olds Motor Works was organized to build automobiles; this pioneer company was followed by the organization of the Buick

Auto-Vim and Power Company in 1901, the Cadillac Automobile Company in 1902, and the Ford Motor Company in 1903.

STUDY QUESTIONS

1. What is meant by progress in transportation?
2. Why have new forms of transportation often been opposed?
3. In what respects has the progress in transportation changed civilization?
4. In what respects must the railroad compete with the automobile and the airplane if it is to survive?
5. Point out the advantages of each type of transportation.
6. Discuss the problems created by competition in transportation. How have these problems been coped with in our democracy? What problems remain unsolved? What new problems are now arising? Are these similar problems created by competition in other industries in the United States? What is being done to solve these problems?
7. What values must be conserved in solving problems of wasteful duplication of effort and inefficient, uncoördinated operation, in order to preserve the fertility of invention and the opportunity for change in a democracy?
8. What would be the relative advantages and disadvantages of government ownership and operation of the railroads?
9. Why is water transportation still the cheapest form of transportation?
10. How are the railroads meeting the new competition created by automobiles, trucks, buses, and airplanes?
11. Do you know of any legislation in recent days that suggests the possibility that one group of transportation interests is substituting political pressure for research, and thus delaying progress in transportation, which was so characteristic of the early history of transportation?

UNIT V

SECTION 5

THE INTERNAL-COMBUSTION ENGINE IS ONE OF THE GREATEST DEVELOPMENTS OF MODERN CIVILIZATION[1]

Introduction.

> The greatest thing civilization has had thus far is the internal combustion engine. For the first time in the history of the world mankind has had a small, mobile, inanimate power device. The greatest factor that has caused the development of all our civilizing devices has been the use of inanimate power. The internal combustion engine has absolutely changed our whole method of living. The city has developed because of its wonderful system of electrical distribution. Back of this is a great power unit. If the power unit stops, the lights go out and the motors stop. But with the internal combustion engine we carry with us the power-house. We move it wherever we please. — C. F. Kettering.

The automobile is one of the commonest pieces of machinery in everyday use; more than thirty million are in daily use upon our roads. It has become so necessary in our modern life that it has been called the "fourth necessity," giving way only to food, clothing, and shelter.

The internal-combustion engine, exemplified by the ordinary automobile engine, is more efficient than the combination of a steam engine and boiler. In this case the boiler is not necessary, because the combustion of the powdered coal, fuel oil, kerosene, gasoline, natural gas, or other fuel takes place within the cylinder of the engine itself and thus eliminates the heat losses of the boiler.

The internal-combustion engine is much lighter in weight than the steam engine-boiler combination in comparison with the power developed. Internal-combustion engines also possess the advantage of compactness, ease, and quickness of starting and stopping, along with ease of attachment to machines to be operated.

Since internal-combustion engines are used widely by nearly everybody in the form of automobiles, tractors, airplanes, motor boats, power and light plants, graders, motorcycles, pumps, and scores of

[1] Most of the material in this Section has been selected from the booklets, *When the Wheels Revolve* and *Diesel, the Modern Power*, through the courtesy of the General Motors Corporation.

other machines, it is important that everyone understands the principles of their operation.

The Automobile Is a Combination of Simple Machines.

The parts and method of operation of the gasoline engine are quite simple in their elementary form. Let us start with the cylinder. It is merely a tube closed at one end, about the same size and proportions as a tall coffee can. A piece of pipe with one end closed would also make a cylinder. Many engines used in early automobiles actually had cylinders made from cast-iron pipe.

Inside this cylinder a closely fitting piston slides up and down. This combination gives us a pump similar to the familiar tire pump. Each time the piston moves up and down, air is pumped. An automobile engine pumps from twenty-five to fifty gallons of air mixed with from 0.4 to one pint of gasoline for each mile it travels. The figures depend upon the size of the engine.

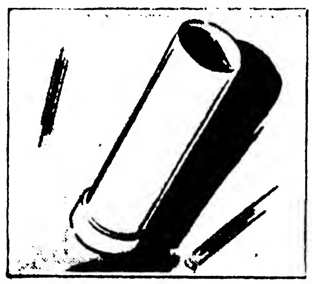


FIG. 110.

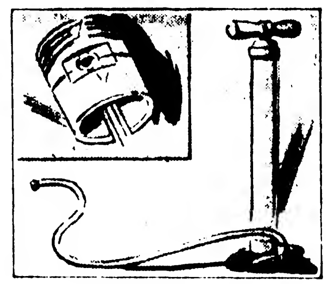


FIG. 111.

This up-and-down movement must be converted into rotary movement to propel the car. The crankshaft and connecting rod of the engine do this. A crankshaft is familiar in the form of the crank for a kitchen meat grinder, emery wheel, or foot pedal of a bicycle. The hand crank is the crankshaft; your arm or leg, as the case may be, is the connecting rod. At the maximum speed of the car the crankshaft may be revolving over 4500 times a minute. Each time the crankshaft makes one revolution, the car moves ahead about half a yard. When we build engines with more than one cylinder, the crankshaft has a number of cranks.

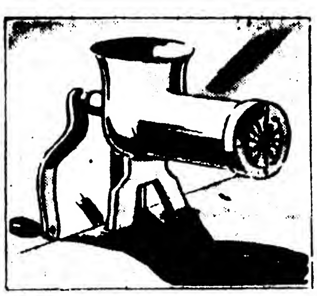


FIG. 112.

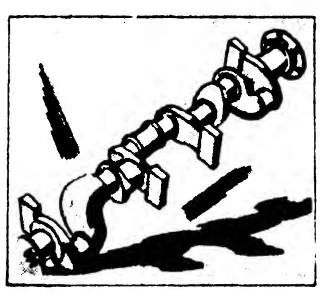


FIG. 113.

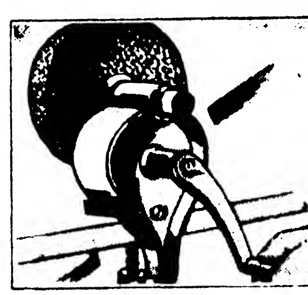


FIG. 114.

On the end of the crankshaft, a heavy wheel called a flywheel is mounted. If we turn the emery wheel by hand very rapidly and then let go, the wheel will continue to revolve. This is similar to the flywheel. It keeps the engine turning between power impulses.

By combining the tire pump and emery wheel we obtain a good air pump. Let us take this air pump and add the things necessary to change it into an engine. Additions must be made to the air pump to allow it to pump a mixture of air and gasoline.

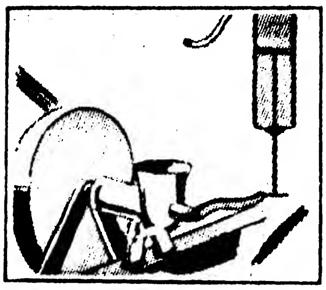


FIG. 115.

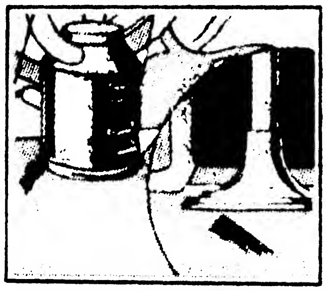


FIG. 116.

The engine must have doors which will open and close to allow the mixture of gasoline and air to enter the cylinder and the burned gases to pass out again at the proper time. The drafts on your stove or furnace control the intake of air and outlet of burned gases. Likewise, the valves in the engine let in or allow the gases to be expelled. In the furnace we can take our time about opening and closing the drafts, but in the engine the valves must open and close in less than one hundredth of a second.

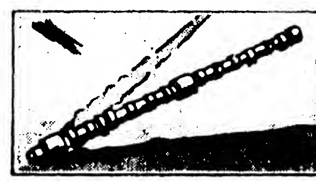


FIG. 117.

It is necessary to open and close the valve automatically at exactly the right time. The cams and shaft are provided to do this. A cam is a device to convert rotary motion into up-and-down motion of the valves. The cam works something like the off-center wheel on the wheelbarrow pictured in the illustration. The camshaft is made up of a series of cams, a cam for each valve. The camshaft is driven by the crankshaft and rotates at exactly one-half the speed of the crankshaft.

The automobile engine takes a mixture of gasoline and air in the correct proportions and burns it in the cylinder. To mix air properly with liquid gasoline requires the carburetor. The carburetor operates

FIG. 118.

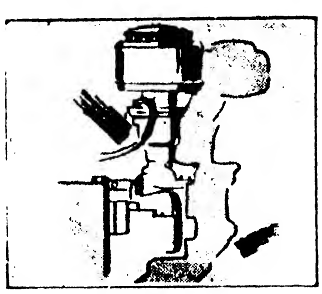


FIG. 119.

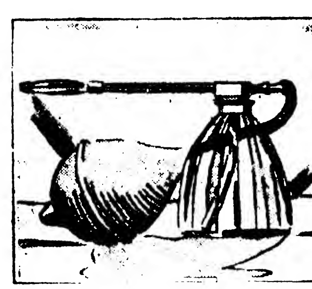


FIG. 120.

much like the atomizer or like the fly-sprayer. Air, rushing past an open tube of the correct size, picks up the liquid and mixes it with the air. For every pound of gasoline, about fifteen pounds of air are normally necessary to obtain the correct proportions for a good burnable mixture. The air contained in a room ten feet square and twelve feet high is barely enough for the combustion of each gallon of gasoline.

For starting and for accelerating, a richer mixture is necessary. Various devices built into the carburetor make it possible to obtain a mixture containing more pounds of gasoline for each pound of air on starting.

At the top of the cylinder, above the piston, is a space called the "combustion chamber," where the mixture of air and gasoline is burned. It is into this space that the mixture is compressed. If the space is small, the gas is compressed very much. If the space is large, it is not compressed as much. We call an engine with a small space *a high-compression engine.*

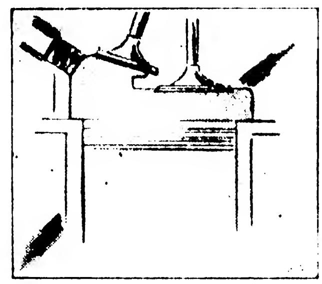


FIG. 121.

Compression ratio is the fancy term used to describe the extent of the compression in the combustion chamber. The volume of the cylinder and combustion chamber is measured in cubic inches, although we could just as easily use quarts or gallons.

To obtain the value for compression ratio, let us take one cylinder of an engine. Turn the crankshaft over until the piston is at the bottom of the cylinder. Now let us measure the volume of the space above the piston including the combustion chamber. To do this, we can fill the space with oil and then drain the oil out and measure its volume. Suppose we find we have 50 cubic inches of oil.

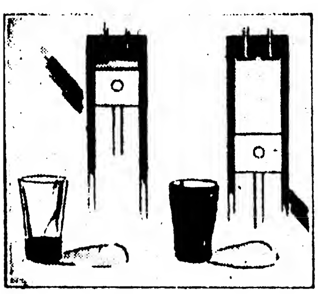


FIG. 122.

Then let us turn the crankshaft until the piston is at the top of the cylinder. Again we fill the space above the piston with oil and measure its volume. Suppose we find it is 10 cubic inches. The compression ratio is then the volume with the piston at the bottom divided by the volume with the piston at the top. In other words, 50 divided by 10 equal 5. The compression ratio is then 5 to 1.

This means that if the cylinder is full of gas when the piston is at the bottom, the gas will occupy only one fifth of the volume when the piston is at the top. That is all there is to compression ratio. The value for compression ratio in automobile engines varies between about 5 to 1 and $7\frac{1}{4}$ to 1.

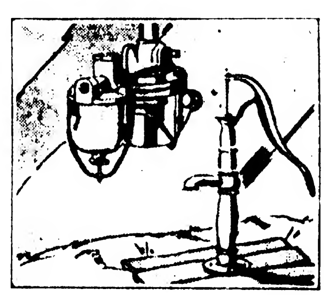


FIG. 123.

To bring the liquid gasoline to the carburetor from the tank in the rear requires the fuel pump. It operates in a manner similar to the old water pump. Each stroke of the pump pulls gasoline from the tank in the rear and deposits it in the carburetor.

All the above operations must go on in an orderly fashion, each event

occurring at the proper time and for the right duration of time. The schedule on which the engine runs to do this is called the four-stroke cycle. A stroke is one movement of the piston from one end of the cylinder to the other: from top to bottom, or from bottom to top. The four-stroke cycle simply means that the schedule each cylinder works on requires four strokes of the piston — first down, then up, again down, and up.

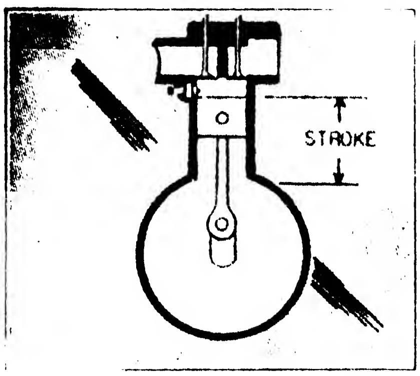


FIG. 124.

A four-cycle engine and a cannon have much in common. They both go through the same operations each time they fire. In the engine, the first downstroke of the piston is the intake stroke which reduces the pressure, so that the mixture is forced by the atmospheric pressure into the cylinder. At the bottom of the stroke, when the cylinder is full, the intake valve closes. This is the operation of loading in the cannon.

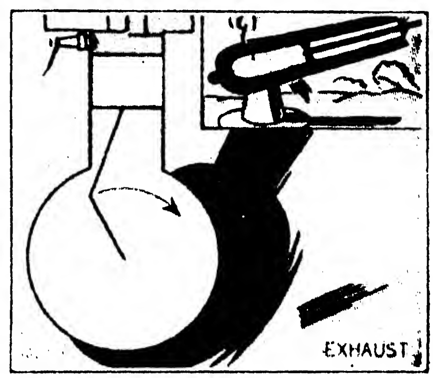


FIG. 125.

The next upstroke of the piston, the compression stroke, compresses the mixture into the small space in the cylinder head. In the cannon it is also necessary to compress the powder. In the engine, the pressure is increased from approximately that of the atmosphere to 180 pounds per square inch. This is three or four times the pressure carried in an automobile tire.

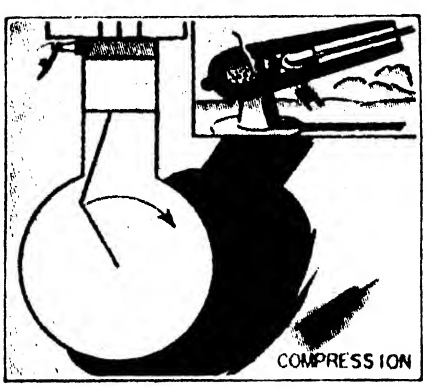


FIG. 126.

Between the second and third strokes firing occurs. In the cannon the initial fire may be supplied by a match. In the engine an electric spark occurs at exactly the right time after the gas is compressed. The pressure in the cylinder is raised to about 400 pounds per square inch in a fraction of a second by the burning of the mixture of air and gasoline. The burning of powder produces a high pressure in the cannon.

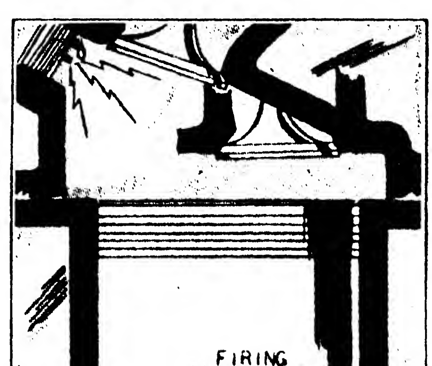


FIG. 127.

The next downstroke is the power stroke. The hot gases, expanding against the wall of the enclosed chamber, push the piston, the only movable part, downward. In the

cannon the movable part is the ball which is forced out of the mouth of the cannon by the burning of the powder.

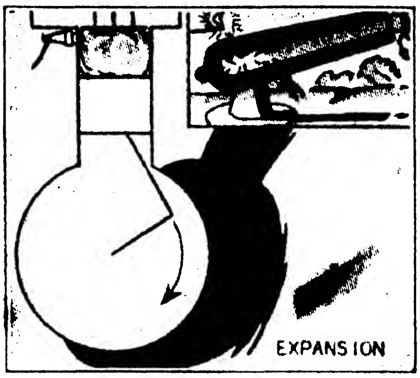


FIG. 128.

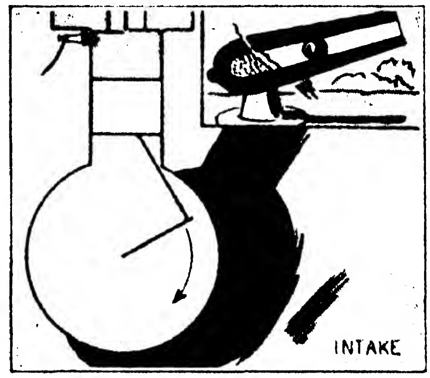


FIG. 129.

The last stroke is the exhaust stroke. The gases have now spent their energy in pushing the piston downward, and it is necessary to clear the cylinder to make room for a new charge. The exhaust valve opens, and

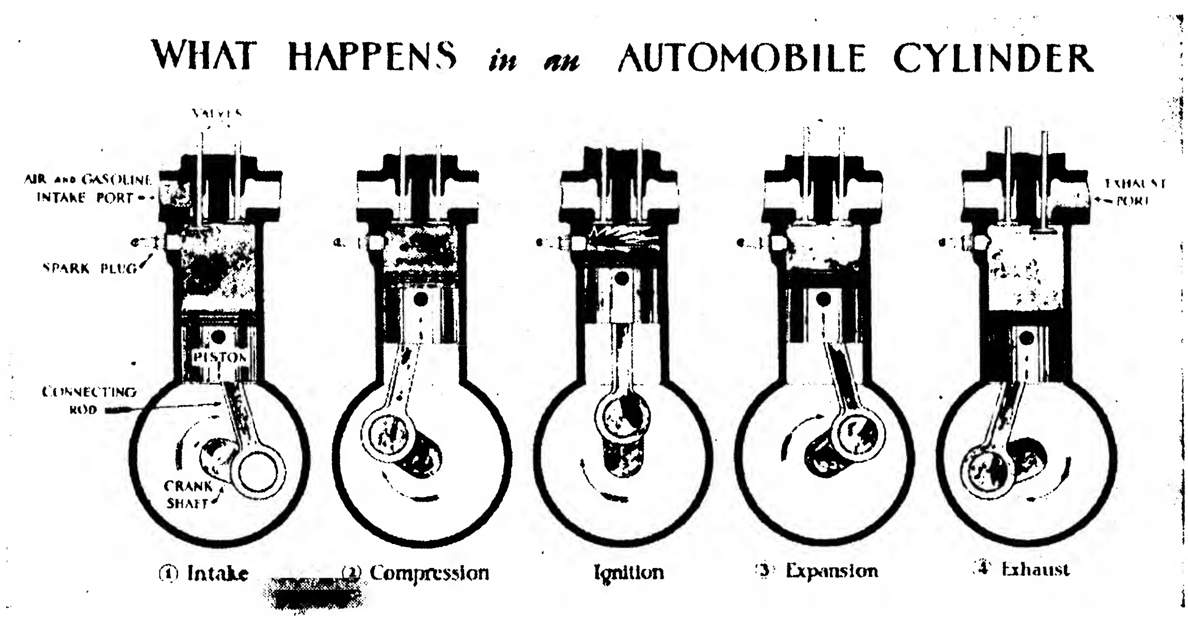


FIG. 130.

the piston, moving upward, forces the burned gases out. In the cannon, the ramrod is used to clear the burned powder out of the cannon barrel.

The light which starts the mixture burning is the electric discharge between the points of the spark plug. The spark must start the mixture burning at the right instant. The distributor sees to it that each spark plug *fires* at the correct time.

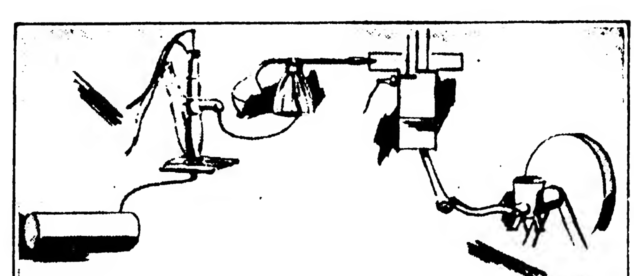


FIG. 131.

Let us summarize the information we now have about the engine. Its operation is very simple. A fuel pump brings the gasoline to the carburetor. The carburetor

mixes it in the right proportions with air and delivers it to the cylinders through the valves. The mixture is burned in the cylinder, and mechanical power results. The piston moves up and down, which causes the crankshaft to rotate. We now have the chemical energy in the gasoline converted into useful work.

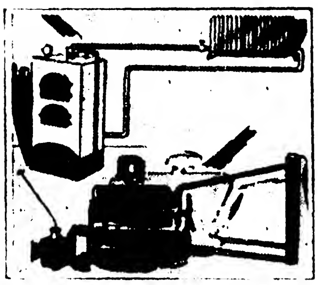


FIG. 132.

Automobile Engines Must Be Cooled.

Temperatures of 4000° to 4500° F., or almost twice the temperature necessary to melt iron, are produced in the cylinder. If cooling were not provided, the pistons, valves, and cylinder head would be only a molten, misshapen piece of metal in a short time. The easiest way to cool the engine is to provide a water jacket around the hottest parts to carry away the heat.

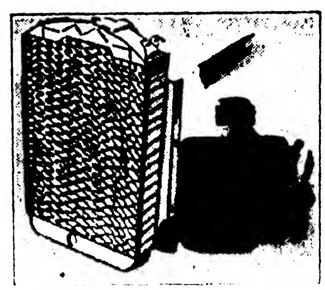


FIG. 133.

Let us consider the engine, from the cooling standpoint, as a device for producing heat and liberating it to the air. Another such device is a furnace. The problem of the cooling system is therefore very similar to that of the heating system in your home. In the engine, heat is taken up by the water in the jackets and conveyed to the radiator, where the heat in the water is given up to the air. The action of the hot-water or steam furnace is similar. The furnace boiler is the engine, the steam radiators the radiator on the car.

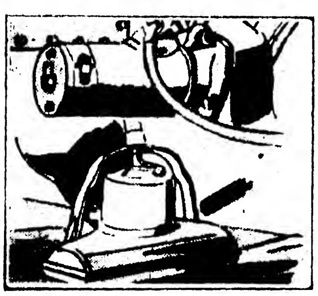


FIG. 134.

The Storage Battery Makes Possible the Electric Starter.

Now that we have a complete engine, we must have a method of starting it, since it will not start by itself. The engine must be turning over before it can run under its own power. To give the engine the initial start, an electric motor is used.

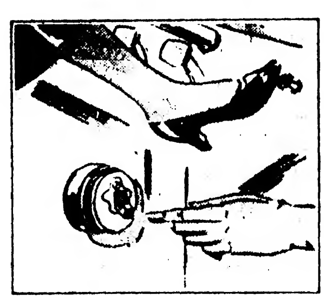


FIG. 135.

The starter pedal or button is nothing but an electric switch like a wall switch which turns on the lights in a room. In the Bendix drive, pushing the starting-button connects the motor to the battery. The inertia of the pinion causes it to be screwed forward into engagement with the flywheel gear. When the pinion is fully engaged, the motor is revolving at about 400 R.P.M. and the pinion not at all. The momentum of the armature

starts the engine turning over by reason of a spring between the armature and the pinion.

The Clutch Connects the Engine with the Rear Wheels.

At this point we have a complete engine with a method of both starting and cooling it. The next step is to transfer the power or turning-effort back to the road wheels. It is necessary to be able to disconnect the engine and rear wheels. The engine must be able to run when the car is stationary. A mechanism called a clutch, operated by a foot pedal, does this. Suppose we mount two ordinary pie plates, each on a shaft, as shown in the illustration. Holding the shaft loosely in the hand, set one disk spinning. The other one can be started spinning by bringing it into contact with the first one. This is the principle of the single-disk clutch used on most automobiles. One plate is fixed to the flywheel, the other to the transmission. Moving the two plates together connects the flywheel with the transmission.

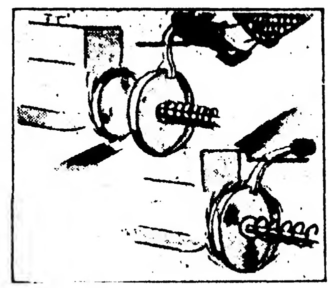


FIG. 136.

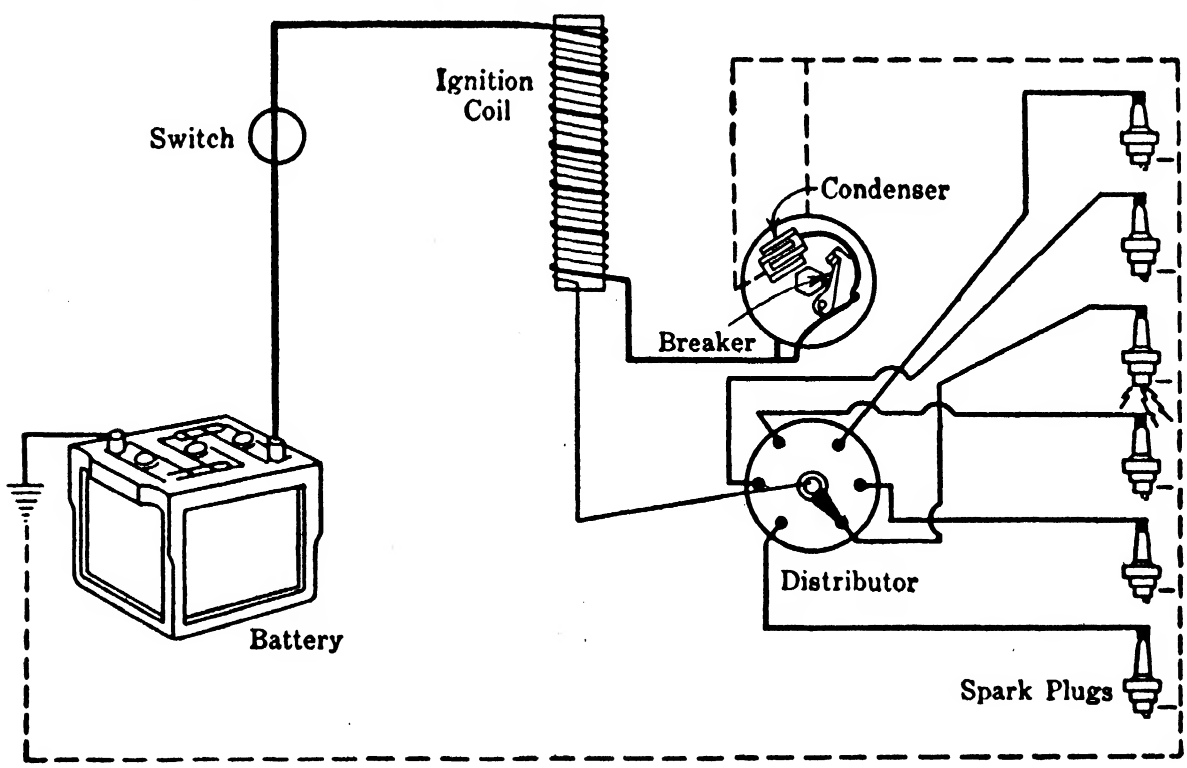


FIG. 137.

The Gears Enable One to Choose the Relationship of the Speed of the Engine to That of the Rear Wheels.

More work has to be done when an automobile goes uphill than when it travels the same distance on the level. Either a greater force will have to be exerted to maintain the same speed, or the speed will have to be decreased if the power remains unchanged. Automobiles, there-

fore, have a system of gears which can be shifted so as to change the speed ratio. Low-speed combinations of gears are used in starting as well as in climbing hills because more power is required to accelerate a car than to keep it going after it is once in motion. The automobile engine develops its greatest power when it is turning fast. It is therefore necessary to be able to allow the engine to run fast, even though the car is going slowly. To do this gives high turning-effort at the rear wheels for rapid pickup, good hill climbing, and heavy pulling. When the car gets up to speed, it is necessary to allow the engine to run more slowly. The transmission, or as our English cousins call it, the gearbox, accomplishes this for us. To demonstrate this action, take an ordinary clock. The hour hand moves slowly and is very difficult to stop with your finger. The minute hand is much easier to stop, and the second hand requires but a touch. This is the principle of a three-speed transmission. In low, we have great turning-effort at the rear wheels, while in high we have high car speed. Second speed is intermediate between low and high. Varying the size of the gears varies the speed. For a three-speed transmission we simply have three sets of gears of different sizes and a method of allowing the driver to choose the set of gears he wishes to use. The gear-shift lever allows the driver to choose any gear set — low, second, neutral, high (direct connection), or reverse — whichever he needs. The third set reverses the direction of rotation and allows us to back up.

The Diesel Engine Is a High-Compression Internal Combustion Engine.

In a Diesel engine the compression ratio is far above that used for even the highest compression-ratio automobile engine. The greatest difference in the two types of engines is this difference in compression ratio.

In an internal-combustion engine, either a Diesel or gasoline type, the higher the compression ratio the greater the efficiency. The compression ratio of automobile engines has been increased year by year for fifteen years. Each increase has resulted in more efficient engines and has required better, more expensive fuels. The greater efficiency of the *high-compression* automobile engine results in greater power for the same cylinder volume and less fuel consumption. In terms of performance of the automobile on the road, it has meant more miles per gallon, higher speeds, better hill climb, and faster "get-away."

The above explanation may be summed up by comparing the action of the Diesel and gasoline engines with a sled on an icy hill.

Suppose we have a long hill, as shown in the illustration. If we have the operation as we do in the gasoline engine, we would start our slide

one sixth of the distance from the top. In the operation representing the Diesel engine, we would start the sled only *one sixteenth* of the distance from the top. We know that the sled which started the nearer to the top would be able to transmit the greatest amount of energy by the time it reached the bottom. By similar reasoning, we also know that the piston of an engine which starts with the hot gases at a higher level of pressure transmits the greatest energy per cycle. Both the sled and the piston of the Diesel engine would do more useful work than the sled and piston of the gasoline engine. We would therefore get more work out of the Diesel sled. This is another way of saying that the Diesel engine is more efficient than the gasoline engine.

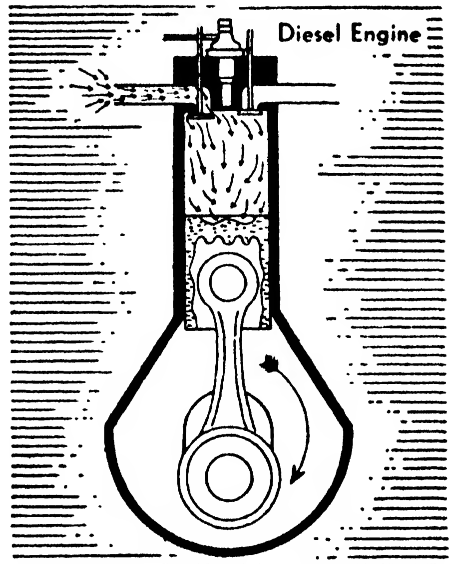


FIG. 138.

Air Only Is Compressed in the Diesel Engine.

When the charge is compressed as much as 16 times, it is heated to about 1000° F. If we increased the compression ratio in a gasoline engine to 16 to 1, this high temperature would start the mixture of air and gasoline burning in the cylinder long before it should. The mixture would start burning while the piston was on its upstroke and cause a violent "knock" or even force the piston back down the cylinder and cause the engine to start running backwards. Even the best commercial antiknock gasoline would not stop this fuel knock. To prevent this premature burning in the Diesel engine, only air is compressed. This is the first difference between the Diesel engine and the gasoline engine. *Only air is compressed in the Diesel engine, and a mixture of air and gasoline is compressed in the gasoline engine.*

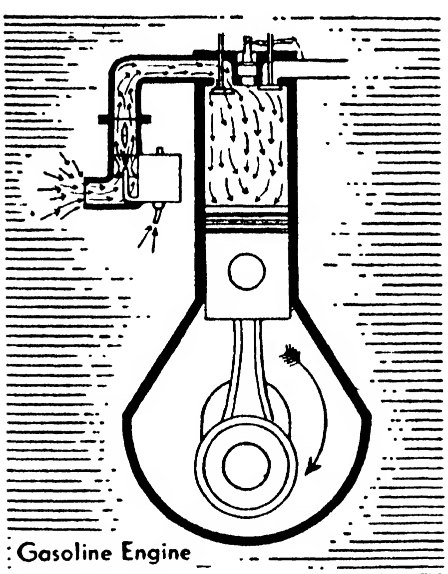


FIG. 139.

A Fuel Injector Replaces the Carburetor in the Diesel Engine.

The carburetor is therefore unnecessary in the Diesel engine because its only purpose is to mix air and gasoline in the correct proportions *before* they enter the cylinder. Compressing the air until its temperature reaches 1000° means that the fuel, which would start burning at 450°, must not enter until the engine is ready to burn it. A fuel-

injection system is the device used to blow, or force, the fuel into this superheated air just before the piston reaches the top of the stroke. There is this difference between the ways the Diesel engine and gasoline engine handle the fuel. The gasoline engine uses a carburetor to mix air and gasoline before it is compressed. The Diesel engine uses an injection system to force the fuel into the cylinder after the air is compressed.

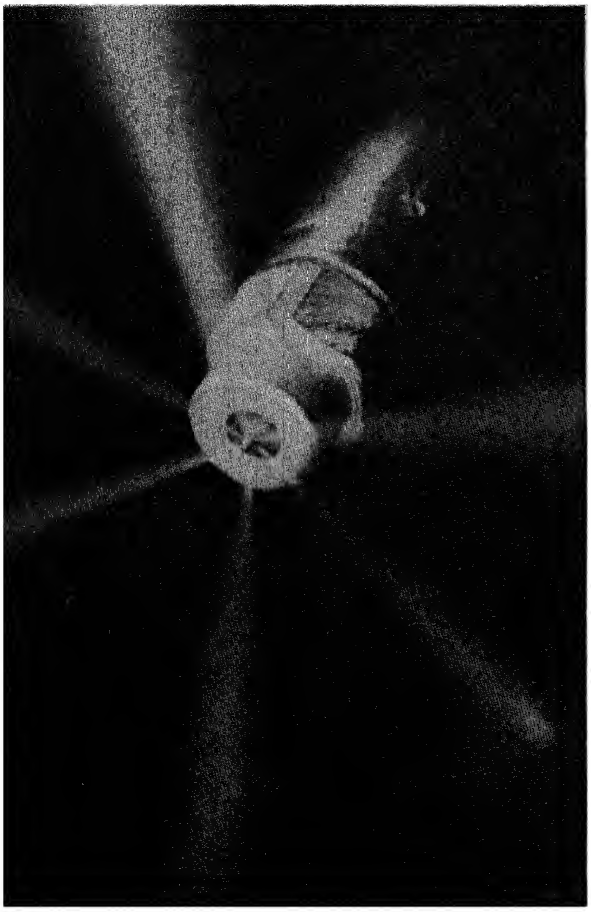


FIG. 140. Photograph of oil spray from an injector.

The heart of the Diesel engine is the *fuel-injection system.* It is often stated that the Diesel engine is simpler than the gasoline engine because it eliminates the carburetor and ignition system. However, the fuel-injection system in the Diesel engine, which must be substituted for these parts, brings up as many problems as are involved in the carburetor and electric-ignition system. It may even be safely said that, at the present time, the fuel-injection system is somewhat *more costly and difficult to make* than the parts which it replaces.

Ignition Is Accomplished by Compression in the Diesel Engine.

In the gasoline engine, when the mixture is compressed by the upward stroke of the piston, it is necessary to supply a spark to start it burning. The electric-ignition system supplies the spark. In the Diesel engine, compressing the air to 1/16 of its original volume heats it to such a high temperature that the fuel will start burning by itself as soon as it is injected; it catches fire just like the flashing of grease in a frying pan.

The Diesel Engine Has a High Part-load Efficiency.

Engines are not always run to develop their full power and speed. In the automobile we seldom have the foot accelerator all the way down to the floor boards. The smaller the amount of power and speed at which we run, the lower is the efficiency. In the Diesel engine the efficiency does not drop off with a decrease in power output; it actually increases.

It is a common experience that the higher the temperature, the easier and faster the heat will flow. The gasoline engine, with its higher temperature in the cylinder, will transfer heat faster to the cooling water and engine parts than the Diesel engine will. Inasmuch as the heat which goes into the cooling water is wasted, the Diesel engine wastes less of the heat in the fuel, and more of the heat is used to move the piston because the temperature is lower.

FIG. 141. Caterpillar Diesel pulling a combine, covering 3½ to 4 acres per hour. Cost of fuel, 9 cents per hour.

This is one of the fundamental reasons for the higher efficiencies of the Diesel engine. It wastes less heat, at both full and part throttle, because the temperature within the cylinder is always lower than in the gasoline engine.

On its world's record run from Denver to Chicago, the Burlington *Zephyr* burned less than 400 gallons of fuel while averaging 77.6 miles an hour for the entire distance of 1015 miles. The 95-ton train and 84 passengers were carried almost 3 miles for each gallon of fuel oil consumed. Speeds of over 100 miles an hour were reached on this trip.

Diesel Engines Do Not as a Rule Burn Crude Oil.

The Diesel engine requires a petroleum fuel oil which is held to specifications which are comparable to those for the gasoline used in your car. First, it must be fluid enough so it can be pumped and injected into the cylinder. Second, it must be clean, or else the closely fitted parts of the fuel system will wear rapidly, and the fine holes and passages will be plugged. Third, it must have the proper ignition properties so it will burn rapidly when it is injected into the hot compressed air in the cylinder and so the engine will start readily. Fourth, it should be reasonable in price.

The real reasons for the lower fuel costs on a Diesel engine are not only because it burns a cheaper fuel, but because it obtains more useful work from the fuel and because the fuel has a higher energy content per gallon.

The Diesel Engine Has Found Many Applications.

The Diesel engine has long been established on the sea. Yachts, passenger ships, freighters, tugs, trawlers, tankers, and ferries have all been powered by the Diesel engine. In the past several years more boats have used Diesel engines than any other type of engines.

On land the Diesel engine has also found wide application in factories, ice plants, oil-pipe lines, electric power plants, and large office buildings.

Diesel engines are now being used in increasingly large numbers to power railroad locomotives, large trucks, busses, tractors, and even airplanes, all due to the introduction of the high-speed Diesel.

In their present state of development the gasoline engine is still superior to the Diesel engine for automobiles.

STUDY QUESTIONS

1. What is the purpose of a flywheel in an automobile engine?
2. What are the functions of (*a*) the valves, (*b*) the carburetor, (*c*) the spark plugs, (*d*) the water, (*e*) the clutch, (*f*) the transmission, (*g*) the distributor, in an automobile?
3. What is meant by *a high-compression engine?*
4. What happens when the timing is not right in an automobile?
5. Why does an automobile heat up when going up a long, steep grade?
6. How does the Diesel engine differ from other internal-combustion engines?
7. Why is the Diesel engine more efficient than the ordinary automobile engine?
8. What is the advantage of a high-compression engine?
9. Why is a carburetor unnecessary in a Diesel engine?
10. Why is an automobile engine less efficient at low loads than at moderately high loads?
11. Describe the four strokes of a four-cycle engine.

UNIT V

SECTION 6

THE AUTOMOBILE TYPIFIES THE TECHNOLOGICAL PROGRESS, THE SOCIAL CHANGES, AND THE SOCIAL PROBLEMS THUS CREATED BY MODERN PHYSICAL SCIENCE

Perhaps the most revolutionary phenomenon of the past forty years was the growth of the automobile industry in the United States. In 1900, 8000 automobiles were in operation, in 1914 there were 1,700,000 automobiles, and by 1941 there were 32,000,000 of the 80,000,000 automobiles manufactured up to that time still in operation.

The development of automobile transportation created millions of new jobs, changed man's living habits in many ways, increased the tempo of life, made crime more difficult to control, and created many social problems more rapidly than society could organize itself to solve them.

The streets in many of our cities built in the horse-and-buggy days are as inadequate to take care of present-day automobile traffic as our present social organization and ideals based on "horse-and-buggy" rugged individualism are unable to solve the problems of the control of the insane, intoxicated, ruthless, thoughtless, and discourteous pedestrians and automobile drivers who are unfit to walk or drive automobiles on streets and highways.

It is the purpose of this Section to give some basic information to help the automobile owner to operate his automobile more intelligently.

The Development of the Automobile Was the Outstanding Achievement of the Past Generation.

In 1885 *Gottlieb Daimler* patented a vertical high-speed gas engine, which was first used in 1885 to propel a motor bicycle and in 1886 to propel a four-wheel vehicle. The gasoline motor-driven carriage made its first appearance in the United States in 1893. In 1895 there were four automobiles manufactured in the United States. The first automobiles were crude contraptions with chain-driven rear axles and solid tires. Their engines had only one or two cylinders and were very noisy.

In 1895 the first pneumatic automobile tires were introduced. Improvements then piled up rapidly. More cylinders were added; demountable rims were introduced; tires were improved; kerosene lights were replaced by carbide headlights which were, in turn, replaced by electric lights run by a generator. Then the storage battery was added and with it the self-starter. Closed bodies were designed.

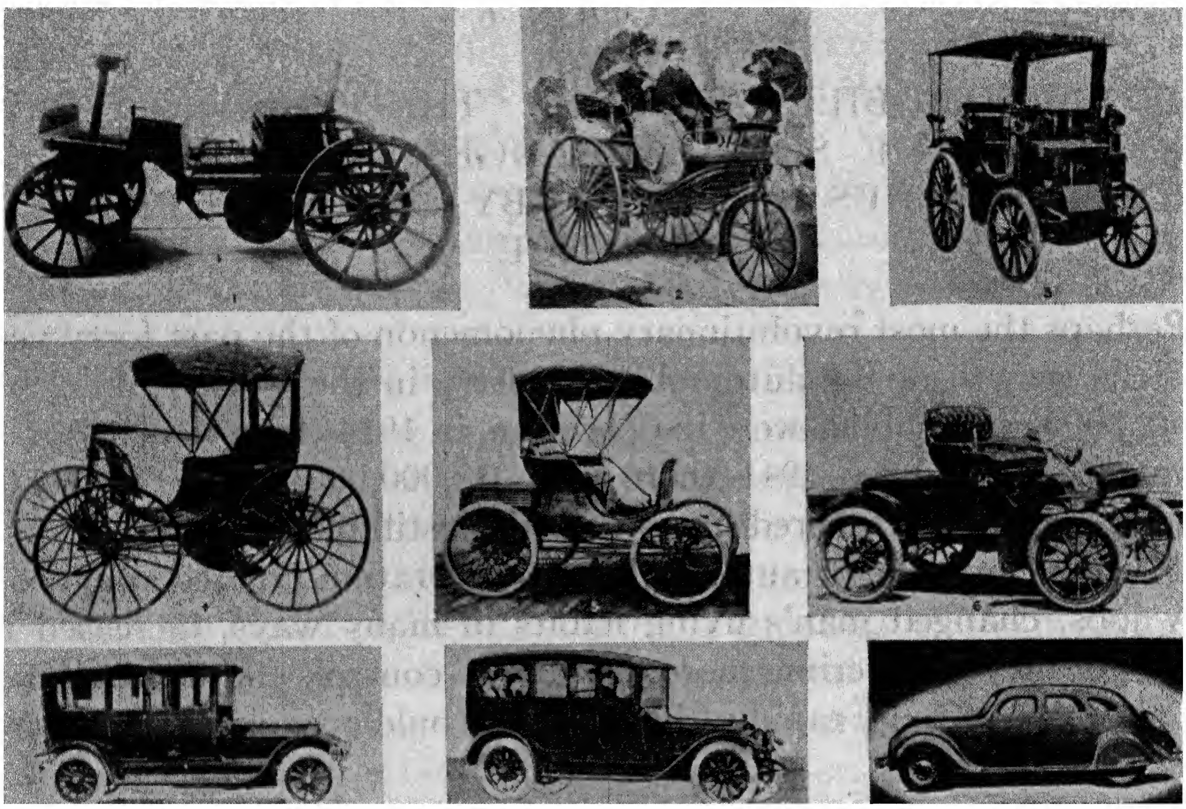


FIG. 142. Evolution of the automobile. (Courtesy of the United States National Museum.)

Increased production required the construction of marvelous new tools and machines, which made possible much better products at less cost. New alloys were used to permit higher-speed and lighter-weight engines and cars. Fuels and the efficiency of engines were improved, although more and more cylinders were added to provide smoother running and greater power.

Highway Expansion Was Stimulated by the Invention of the Automobile.

In 1900 there were only 150 miles of dustless paved highways in the United States. When the weather was dry, dust rose in clouds from the horse-driven vehicles; and when it rained, the wheels sank hub-deep in mud.

The development of highway transportation is one of the most profound and far-reaching contributions to modern life. It has added immeasurably to the national wealth and has added social and cultural enrichment to the lives of the people. Highways have made possible

consolidations of schools and churches and quick movement of farm crops to city markets.

Improved highways have been recognized as an investment rather than an expense because they reduce the operating cost of automobiles by savings in gasoline, tires, depreciation, and repairs and make

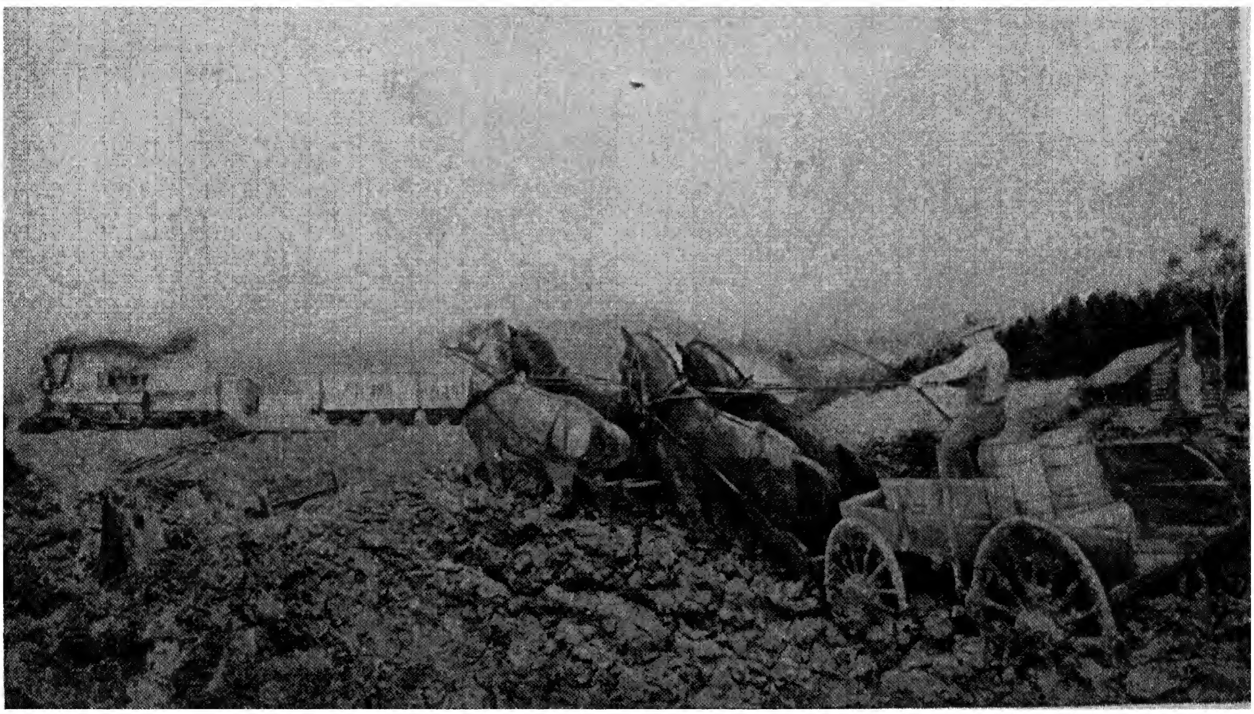


FIG. 143. 1850 — Dark ages of the road. (Courtesy of the Public Roads Administration.)

possible quicker and usually year-round transportation. Improved highways also open up land and markets, and give isolated communities transportation. Over 40,000 towns in the United States are served only by trucks and busses. Highways also have important military value.

The United States had 360,000 miles of surfaced highways in 1920 and 1,172,000 miles in 1940.

There is still room for much highway development. Less than one half of the rural roads are hard-surfaced. Express highways through cities and by-passes which distribute routes around cities are needed to avoid congestion. Traffic congestion reduces gasoline mileage 50 per cent and causes many bent fenders and still more frayed nerves, as well as a considerable loss in time. Few city streets were designed to handle the present automobile traffic. Because railroads were developed before highways, there are now 240,000 railroad grade crossings to be rendered safe.

Modern road-building is a careful scientific process; maps are made, traffic surveys, including the number, type, and weight of vehicles,

character and properties of the soils, the amount of rainfall, and other factors are considered. Experiments show that an ideal grade should not be more than 3 per cent, *i.e.*, a rise of 3 feet in 100 feet of road, and that curves should not be more than 3 degrees, *i.e.*, 3 degrees in 100 feet, thus permitting the driver to see far enough ahead to stop for an obstruction when driving at 70 miles per hour.

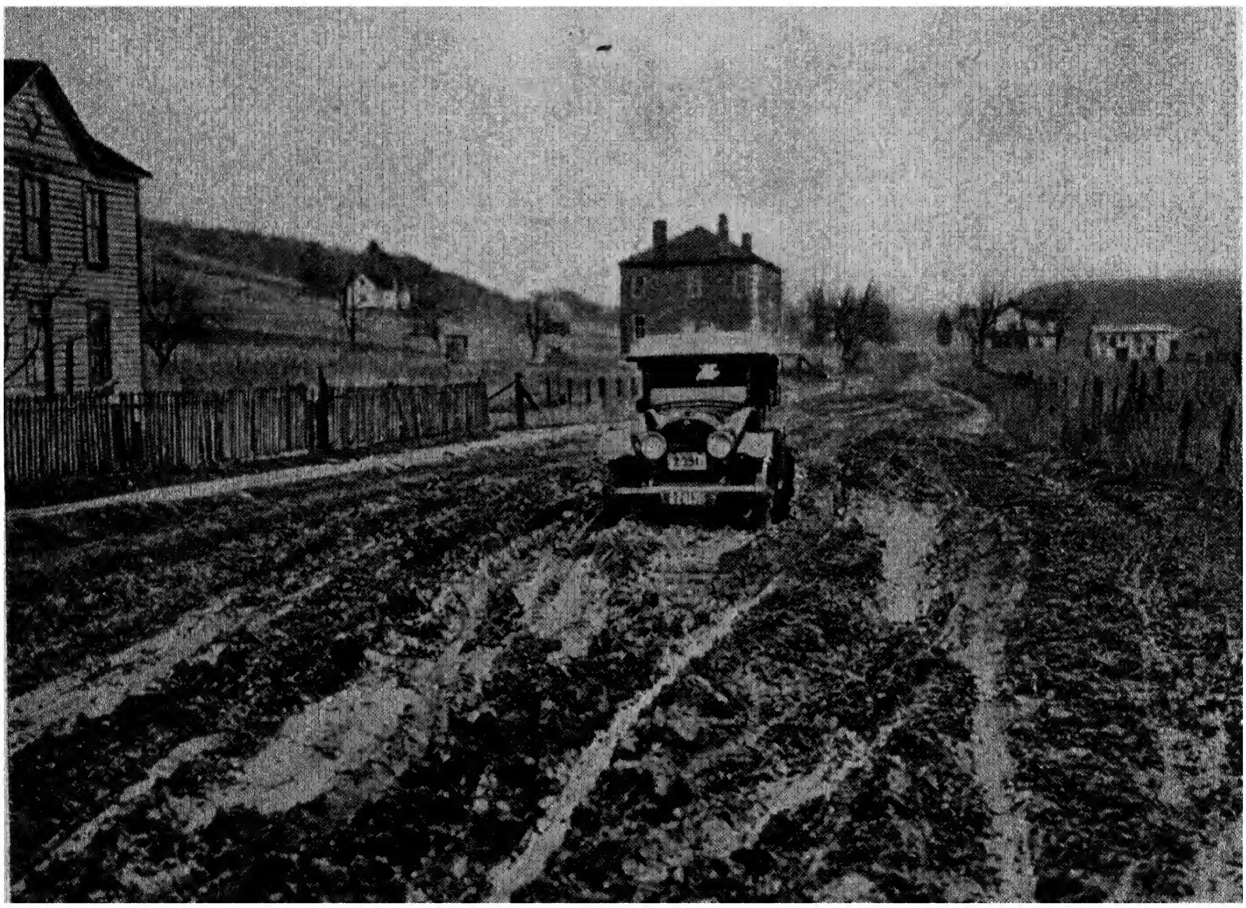


FIG. 144. U. S. 1 between Richmond and Washington in 1919. (Courtesy of the Public Roads Administration.)

Automobile Transportation Has Changed Every Phase of Living.

The popular acceptance of the automobile created the demand for good roads, for which the gasoline taxes paid. As a result the country has been criss-crossed with highways; and filling-stations, lunchrooms, and tourist camps have sprung up like mushrooms.

Much of the increased leisure afforded by the machine age has been used in touring and holiday driving. Country people have visited the amusement places of the city, and city people have gone to the country for outings. Golf courses, bathing beaches, camping in the mountains, visits to national parks, and tours of the whole country have come within the reach of the masses. At least 25 per cent of automobile *trips* are devoted to recreation as reported by the Automobile Manufacturers Association in a survey covering 3,400,000 motorists. The

same survey showed 45 per cent of the car *miles* were for recreational and social uses. Perhaps nothing has done more in leveling the classes in the United States, because the masses are able to enjoy the use of the same highways, city streets, and national parks that the rich man can.

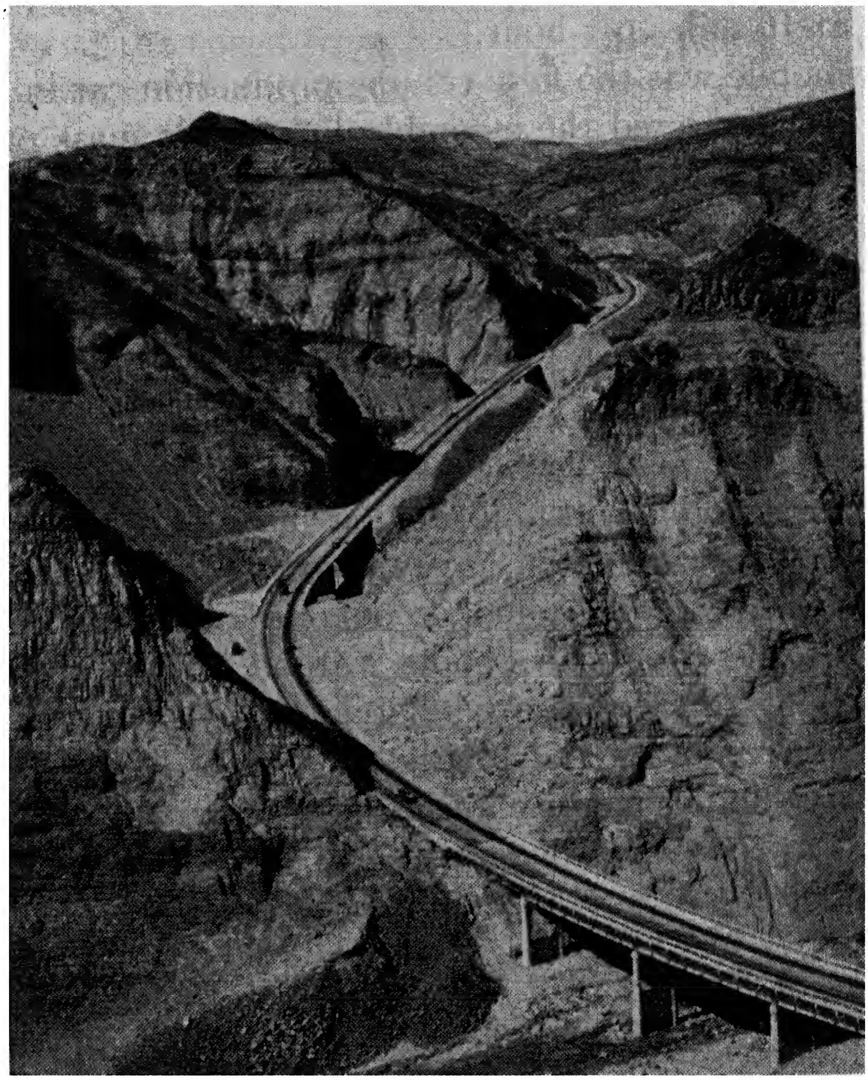


FIG. 145. A modern mountain highway. U. S. 99 in Los Angeles County, California. (Official photograph of the California Division of Highways.)

The Cost of Operating Early Automobiles Was Very High.

In 1911 a Ford touring-car could be purchased for $780; but in spite of this fact, automobiles were restricted to the wealthy because their cost of operation was so high — over 10 cents per mile. New tires cost over twice as much as they do today and lasted less than 1/5 as long. New parts were higher in price and were needed more often.

The Plaything of the Wealthy Has Become a Necessity of the Masses.

There were few paved highways; and one had to contend with clouds of dust, rough roads, sharp turns, and mud whenever it rained.

Filling-stations and free air were scarce. One had to carry a complete set of tools, a pump, tire chains, and extra gasoline. Elaborate clothing was required to keep out the dust.

Speed-mad motorists, driving at 30 miles an hour, frightened horses and overturned carriages on narrow roads with the result that New York State set the top speed in the country at 20 miles per hour, and in the city at 10 miles per hour.

The Oldsmobile was the first volume-production car in 1901.

Henry Ford pioneered the assembly line in the mass production of automobiles and sold them for as little as $400. By 1914 there were about half a million model T's on the road.

Improved gasoline at a much lower cost has been responsible for the chief decrease in the cost of operating automobiles, although better tires and improved lubricants have done their share. The main trend in the development of the automobile itself has been that of increased reliability, speed, engine efficiency, safety, comfort, and beauty, rather than decreased gasoline consumption per mile.

Automobile manufacturers have devoted their research to the production of the kind of automobile that their customer research staff indicated that the American people wanted. The American people have been willing to sacrifice other things to ride like kings, and their vast petroleum resources and high standards of living have made it possible. Why should one buy an inexpensive small car when he can buy the most expensive cars of a few years back at less cost at a used-car lot?

The Economy of Operation of an Automobile Depends upon How It Is Driven.

Unnecessary use of brakes wears them out and decreases the miles obtained per gallon of gasoline. Rapid approaches to stop signs, jamming on the brakes, and then accelerating wide open at the go-ahead signal may save a few seconds, but it may also use three times as much gasoline.

Gears are placed in an automobile to permit economical operation they provide greater pulling power for an engine of a given horsepower when required, thus making it unnecessary to operate an engine on level roads which would be powerful enough to climb hills in high gear.

According to a study made by the *Automotive News*, an engine in good condition will consume a pint of oil on a 1000-mile trip at 25 miles per hour, while it uses 4½ quarts when driven at 65 miles per hour.

Between these two speeds the gasoline consumption will increase 60 per cent, the tire wear will increase 700 per cent, the average main-

tenance costs increase 325 per cent, and the over-all cost per mile, using typical operation costs at the time the study was made, leaps from 1.444 cents to 3.86 cents.

A speed of 55 miles per hour is relatively economical. If one pushes the speed up to 65 miles per hour, 2.8 hours will be saved in a 1000-mile trip; but the extra cost, using typical 1940 figures, would be $8.30. Before increasing the speed from 55 to 65 miles per hour, one should decide whether or not the time saved will be worth the extra $2.96 per hour that it will cost.

Overheating increases oil consumption. Overheating may be due to a worn fan belt, an improper adjustment of the timing or of the carburetor, a clogged-up radiator, lack of water in the radiator, and other factors which may be grouped under the term maintenance. It is not economical to neglect the maintenance of an automobile.

Rapid acceleration is harmful to automobiles. Special care should be taken in breaking in new automobiles to idle them a few minutes before starting, to accelerate gradually at all times, and to use gears on grades in order to provide proper lubrication for the tight-fitting parts.

Continuous operation of automobiles at slow speeds is not desirable because the automobile should be frequently heated up enough to drive off crankcase diluents and condensates.

A Few Driving Errors.

Demonstrating pickup by getting into "50" in less than a block.
Overloading automobiles and trucks.
Racing an engine to warm it up.
Laboring up a steep hill in high.
Pulling down to low speeds while in high gear.
Driving thousands of miles without adjustments.

Lubrication Is the Most Important Factor in Determining the Length of Life of an Automobile.

When cool, an oil must not be so thick that it will not circulate readily. The greatest wear occurs when starting the automobile because the oil is not given an opportunity to lubricate the pistons until the engine is started. Because cold oil pumps slowly, the oil should be warmed up before speeding up the engine. On the other hand, the oil must not become too thin when heated or it will not lubricate properly. Cool oil is colder in the winter than it is in the summer, and yet it will be just as hot in the engine after it has been running for some time. Every lubricating oil represents a compromise, and the wise driver will select an oil that represents a compromise rather than an extreme. Oil does not oxidize as rapidly as it accumu-

lates dirt, in spite of air filters and oil filters. It should be changed as soon as it becomes gritty, even though it still has good lubricating properties. Good oil filters make oil last longer, but it may be that the oil should be changed before it becomes gritty because it may become diluted with unburned gasoline residues and it may become mixed with water and corrosive sulfur compounds. A general rule is to change the oil every 500 miles in the winter and every 1500 miles in the summer. Crankcase dilution is likely to be much greater in the winter than in the summer.

A heavy lubricating oil will last longer, but it will cut down on the gasoline mileage and it will not give the best lubrication. A lubricating oil is intended to *lubricate*, *seal*, *cool*, and *scavenge* rather than to *last*.

In order to adhere to metal surfaces, a lubricating oil must have a low surface tension. On the other hand, an oil must have a boiling-point high enough to prevent it from vaporizing when in contact with the hot metal surfaces. The higher the boiling-point is, the longer it will last, but also the higher the surface tension will be. Some of the newer oils have substances added to them to lower their surface tension and still keep the advantages of stability toward heat.

Lubricating oil must also seal the space between the piston and the cylinder so that the oil will not slip through and be burned with the gasoline — smoke issuing from the exhaust indicates that the engine is burning oil — and so that gasoline will not leak into the crankcase and dilute the oil. With the close-fitted parts of the modern engines a light oil can be used, but as the engine becomes warm, a heavier oil may be needed. A general rule is that heavier oil should not be used unless the oil consumption at normal driving speeds is increasing. One should use as light an oil as is economically possible.

A Few Lubricating Errors.

- Buying an oil on the basis of its lasting qualities.
- Not changing an oil often enough because the automobile has a good oil filter.
- Not renewing the oil filter.
- Changing the oil on the basis of mileage — a thousand-mile straight run may leave a better oil than five hundred miles of slow driving, starting, and stopping in winter.
- Adding "dopes" to oil, thus upsetting their balance.
- Testing an oil by its feel.
- Selecting an oil on the basis of its color.
- Using too heavy an oil.
- Using too little oil in the crankcase.
- Using too much oil in the crankcase. Keep the crankcase 3/4 full rather than full.

Buying oil on the basis of the geographic location of its source. A refiner can produce a satisfactory lubricating oil from any crude oil.

Failing to use the scientific method in buying an oil. Slogans are effective in advertising, but they must not be confused with facts.

Even with Good Brakes It Takes Time for an Automobile to Stop.

People differ in their reaction time; but on the average, it requires a second between the time the mind decides to put on the brakes and the time that the muscles get into action. It is obvious that the number of feet driven during this "thinking time" varies at different speeds. The distance traveled while using the brakes increases more rapidly than the increase in speed; for example, doubling the speed from 30 to 60 miles per hour increases the distance from 73 feet to 292 feet, or about four times. In general, the stopping-distance follows the square law; doubling the speed quadruples the distance required to stop.

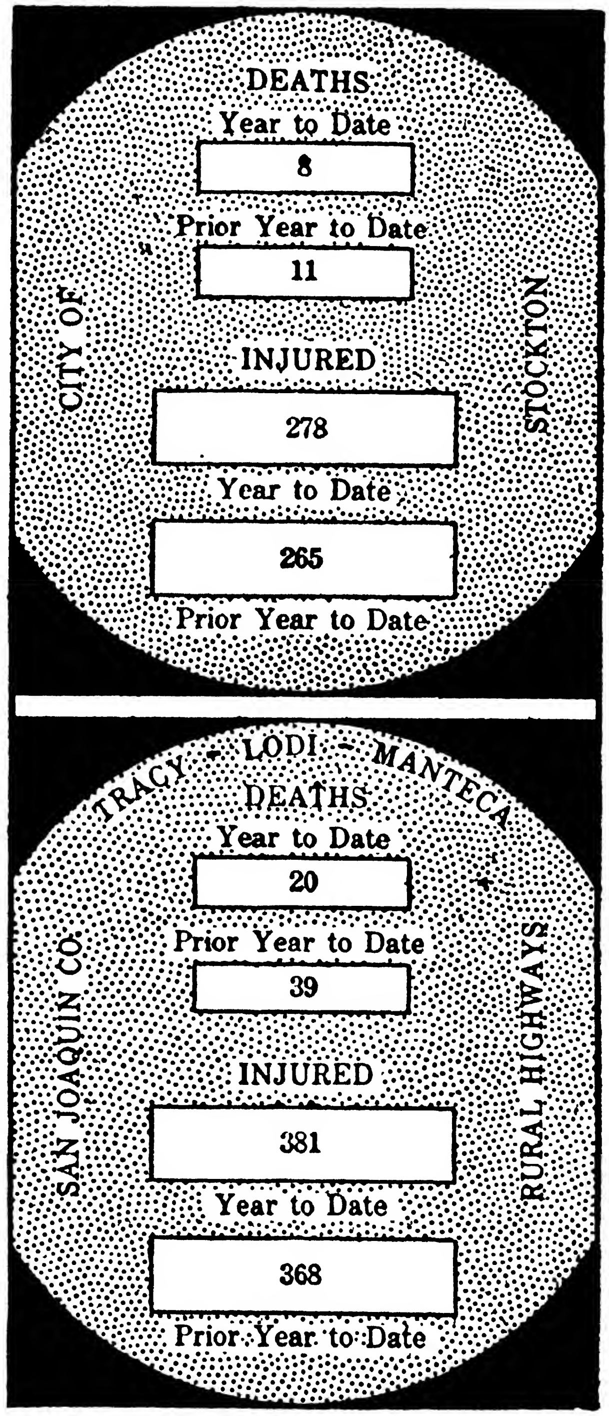


FIG. 146. This is not a report of an air raid; it is a record of the people killed and injured by automobiles in one county in the United States in the period of less than one year.

The Automobile Is Dangerous When Not Properly Controlled.

In the United States 34,400 people were killed and 1,200,000 people were injured in 1940 by automobile drivers. The direct economic losses resulting from traffic accidents were estimated to be $1,600,000,000 in the same year. In England 41,900 civilians were killed by German bombs during the *18*-month period, January 1, 1940–July 1, 1941. England at war was a safer place than American highways.

The automobile driver is the fifth most important death cause, exceeded only by heart disease, cancer, cerebral hemorrhage, and nephritis.

Can some way be found to keep lunatics and the otherwise unfit from driving automobiles?

The psychopathic clinic of the Detroit Recorder's Court examined 467 traffic violators in 1938 and obtained the following startling results:

Insane	7
On verge of insanity	40
Feeble-minded	46
Physical handicaps that made them unsafe drivers	33
Lacked social intelligence	342

Can something be done to keep intoxicated people from driving automobiles? And what shall we do about the intoxication that causes so many pedestrian deaths? Can people be educated to be courteous?

The above questions indicate the immensity of the problems to be solved by modern society.

One of the essentials of social intelligence is courtesy, *i.e.*, thinking of the other fellow.

Characteristics of a Courteous Driver.

1. Parks so as not to obstruct traffic.
2. Slows down in congested districts.
3. Never drives so fast that he cannot stop in the range of his headlights.
4. Dims or tilts his lights when approaching another car.
5. Never drives when intoxicated.
6. Does not drive when very tired.
7. Drives slowly at dusk.
8. At street and road intersections gives the right of way to the car coming toward his right.
9. Warns other cars when he is going to slow down, stop, or turn.
10. Slows down on curves.

Characteristics of a Courteous Pedestrian.

1. Crosses streets only at intersections and with the green light.
2. Does not step out carelessly from behind parked cars.
3. Obeys traffic signals.
4. Does not allow any member of his family to play in the street.
5. Walks on the left side of a highway and carries a flashlight or reflector at night.

Do you realize that you stand a chance of 1 to 12.5 of being killed or injured by an automobile during the next ten years at the present accident rates and that your chances become 50 to 12.5 if you cut out of line of traffic, 21 to 12.5 if you pass another car on a curve, and 10 to 12.5 if you pass a car on a hill?

STUDY QUESTIONS

1. How do modern automobiles differ from those manufactured in 1900?
2. In what respects has highway development affected modern life?
3. What are the major unsolved problems created by the development of highways?
4. In what respects does the development of the automobile typify the impact of physical science on society?
5. What are the social consequences of the development of the automobile?
6. In what respects have our modern highway systems affected society?
7. Why should highways be recognized as an investment rather than an expense?
8. Why has the use of the automobile been more widespread in the United States than in Europe?
9. What have been the major factors in the decrease in the cost of operating an automobile?
10. What have been the major trends in automobile design?
11. Why have automobiles not been designed to yield greater efficiency as have the European automobiles?
12. Why should one not use his brakes unnecessarily?
13. Why should one avoid rapid changes in speed at any time?
14. Why should one use lower gears on grades?
15. What is the effect of high speeds on the cost of operating an automobile?
16. How should a new automobile be broken in?
17. What are some of the rules that a courteous pedestrian would follow?
18. Would it be better to abolish automobiles and thus make it safer to become intoxicated than it would to abolish intoxication? Inasmuch as neither can be abolished, what shall we do?
19. Is intoxication a social or moral problem?
20. Which man is likely to receive the heavier punishment, the man who deliberately runs down a child or the intoxicated driver who "is not responsible for what he does"?
21. What are the causes of overheating an automobile, and why is overheating objectionable?
22. Why should an automobile engine be left running for some time after a long hot drive?
23. Why should a hot automobile engine be left running when pouring cold water into the radiator?
24. List a few driving errors and explain why they are errors.
25. How often should the oil in an automobile crankcase be changed?
26. How heavy an oil should one use in an automobile?
27. What is the cause of a smoky automobile exhaust?
28. What are the functions of an automobile oil?
29. Mention a few lubricating errors and explain why they are errors.
30. Suggest some of the possible improvements that should be found in automobiles ten years hence.
31. List the causes of automobile accidents.
32. Suggest some possible methods of reducing automobile accidents.
33. Give the characteristics of a socially intelligent automobile driver.
34. Give the characteristics of a socially intelligent pedestrian.

UNIT V

SECTION 7

THE AIRPLANE IS A TRIUMPH OF MODERN SCIENCE

We are at the opening verse of the opening page of the chapter of endless possibilities. — Rudyard Kipling.

Introduction.

In 1941 the Douglas Aircraft Company completed its first B–19 bomber — a huge airplane capable of transporting 28 tons of bombs or 125 fully equipped soldiers and having a wingspread of 212 feet, a length of 132 feet, and a height of 42 feet and 9 inches, which is equivalent to that of a three-story building.

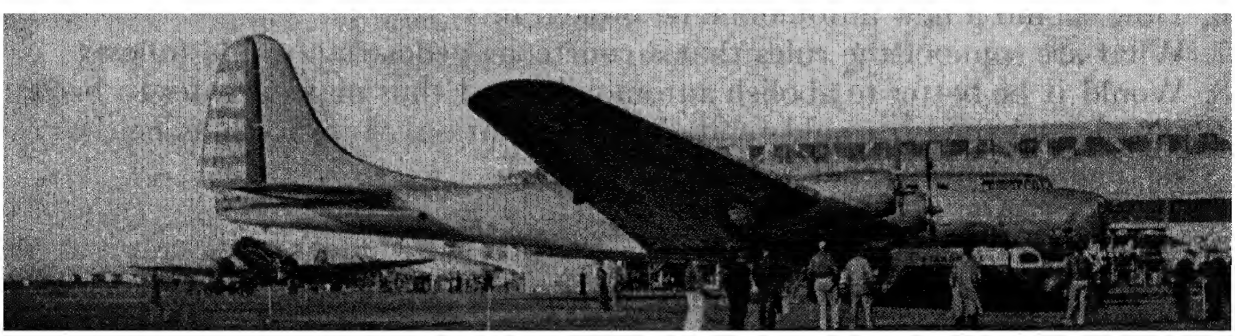


FIG. 147. Douglas B–19. Its mighty wings measure 218 feet from tip to tip. With a fuel capacity of 11,000 gallons, the B–19 can fly from Los Angeles to London and back to New York. (Courtesy of the Douglas Aircraft Company.)

This monster airplane is the largest one ever constructed; although the German Do–X flying boat carried 170 persons, its wing span was only 157 feet, and it could travel only 114 miles per hour as compared with the 210 miles which the B–19 bomber can do.

The real significance of this huge airplane is not so much that it may make feasible round-trip bombing expeditions to Europe as it is that the B–19 bomber represents a great many of the advances of modern physical science and typifies the possibilities of the application of the power of science when applied to warfare. The B–19 will also serve as a testing-laboratory, which will give help in developing the cargo planes of tomorrow.

Five hundred engineers worked for four years, and 750,000 hours of research and engineering time were spent in planning the B–19. Four acres of blueprints were required for the final detailed plans. Ten miles of electrical wiring are contained in this airplane.

Aeronautical engineers stated in 1938 that it would be quite feasible to construct a plane weighing 200 tons, capable of carrying over 300 people 5000 miles at 300 miles per hour.

It is the purpose of this Section to present a brief picture of the tremendous strides that have taken place since December 17, 1903, when two bicycle-dealers, Orville and Wilbur Wright, made their historic flight in their strange contraption of sticks and wires.

A Brief History of Aviation.

1500 — Leonardo da Vinci made designs for wing-flapping machines to be operated by muscular effort.

1742 — Marquis de Bacqueville of France glided 900 feet.

1800–1810 — Sir George Cayley, the father of aerodynamics, discovered the principle of producing stability and constructed a stable glider. He introduced the vertical rudder.

1848 — John Stringfellow and William Henson flew an 8-pound model airplane powered with a small steam engine.

1866 — Herbert Wenham studied the problems of flight and introduced the wind tunnel for testing airplane models.

1896 — Otto Lilienthal of Germany was killed after several years of successful flying with a glider. Octave Chanute continued Lilienthal's experiments. Samuel Langley flew a heavier-than-air machine model with a 1¼-horsepower steam engine 2500 feet, with no one aboard, of course. Langley made great contributions to the science of flying but was jeered at by the public and died of a broken heart.

1899 — Percy Pilcher of England was killed while flying a glider.

1903 — December 17 — Orville Wright and Wilbur Wright, after several years of successful gliding experiments, in which they learned how to control an airplane, produced a gasoline-engine-powered airplane which flew for a quarter of a minute with Orville Wright at the controls. The Wright brothers were careful students, painstaking experimenters, modest, simple, and patient.

1908 — Leon Lelagrange (France) made the first recorded flight in Europe of more than one mile.

1909 — Top speed of airplanes was 46 miles per hour. Louis Bleriot flew over the English Channel, a distance of 21 miles.

1910 — Jorge Chaves flew 75 miles over the Alps but lost his life in a crash landing.

Glenn H. Curtiss flew from Albany to New York, a distance of 143 miles, in 2 hours, 50 minutes. France and Germany took the lead in investigating the possibilities of military airplanes.

1913 — At the beginning of World War I, France and Germany each possessed about 600 military planes, and England 150. Top speed of airplanes was 126 miles per hour. Progress in aviation came to a standstill. Pusher-type airplanes with the propeller behind the pilot gave way to tractor planes with the propeller in front of the plane when it was found possible to synchronize the firing of a machine gun with the propeller.

1919 — Top speed of airplanes was 127 miles per hour. Lieutenant Commander Albert C. Read and his crew flew across the Atlantic Ocean in a flying boat of the American Navy. John Alcock and Arthur Brown made a nonstop flight of 1980 miles from Newfoundland to Ireland in 16 hours at a speed of 120 miles per hour. Ross Smith flew 14,000 miles from London to Australia in a series of hops.

1926 — Roman Franco flew from Spain to Buenos Aires; Richard Byrd and Floyd Bennett flew over the North Pole.

1927 — Francisco de Pinedo, an Italian, completed a well-planned trip that took him to Africa, South America, North America, and Europe, which demonstrated what scientific preparation and navigation can do. Charles A. Lindbergh flew from New York to Paris, a distance of 3325 miles, in 33½ hours. He depended upon dead reckoning for navigation. Perhaps no one in history ever received so many honors in such a brief space of time. Lieutenants Lester J. Maitland and Albert Hegenberger of the United States Army flew from the American mainland to Hawaii, guided by a radio beam.

1928 — Captain Kingsford-Smith and his crew flew the Southern Cross across the Pacific from San Francisco to Brisbane, Australia. Amelia Earhart, with W. Stultz and L. Gordon, was the first woman to cross the Atlantic Ocean in an airplane.

1929 — Rear Admiral Byrd flew over the South Pole.

1930 — Two Frenchmen, Dieudonne Costes and Maurice Bellonte made a nonstop trip from Paris to New York.

1931 — General Italo Balbo flew ten flying boats from Africa to Brazil. Post and Gatty flew around the world in 8 days and 15 hours. Boardman Polando flew from New York to Istanbul nonstop in 49 hours.

1932 — Amelia Earhart made a solo trip from Newfoundland to Ireland.

1933 — Wiley Post completed a solo flight around the world in 7 days, 18 hours, and 49½ minutes.

1937 — Three Russian airmen, Chkalov, Baidukov, and Beliakov, flew nonstop 5288 miles from Moscow, Russia, to Vancouver, British Columbia. Three other Russian airmen soon flew 6262 miles from Moscow to San Jacinto, California.

1938 — Howard Hughes and his crew flew around the world a distance of 14,672 miles in 3 days, 19 hours, 14 minutes, and 10 seconds. A German Heinkel fighting plane averaged 394 miles per hour. A Japanese plane flew 7240 miles nonstop with a crew of three. An Italian plane flew to an altitude of 56,046 feet. A 42-passenger airliner was launched.

1939 — Pan-American clippers inaugurated regular passenger service across the Atlantic Ocean and completed 100 trips on December 20, 1939. The first autogiro air-mail line was established between Camden airport and the Philadelphia post-office roof. Airlines carried 2,045,021 passengers 815,000,000 miles without a fatal accident. A German Messerschmitt attained an average speed of 469 miles per hour.

1940 — Stratosphere flights in airtight cabins were introduced by airlines. Land passenger planes of 25 tons and 4 engines were developed — their capacity is 42 passengers. Air service from the United States to New Zealand and Australia was inaugurated. Airplane engines of 2000 horsepower went into production. A patent was granted for retractable wing pontoons. Neoprene-rubber gasoline tanks became available. Airplanes enabled offensive warfare far to outstrip defensive warfare, in which little progress was made during the period 1918–1940. Airplanes were made which climb a mile per minute — Curtis Model 21–B.

Fig. 148. A P–38 Lockheed interceptor plane which can leave the ground and climb a mile aloft in one minute. Recent tests indicated an airspeed of 458 miles an hour. (Courtesy of the U. S. Army Air Corps.)

Many other noteworthy events in the history of aviation are omitted because of lack of space. This brief history of great flights is but the outward evidence of the tremendous advances made by the designers

of aircraft, the skill of mechanics, the accuracy of navigators, and the service of meteorologists.

There Is a Definite Lag between Fundamental Research and Its Practical Application.

The aerodynamic advantages of an unbraced monoplane were recognized in the days of braced biplanes, but it required the invention of light aluminum alloys of great strength and improved techniques in wood construction to make monoplanes practical.

FIG. 149. SBD Douglas dive-bomber. A low-wing type. (Courtesy of the Douglas Aircraft Company.)

The advantages of retractable landing gears and wheels were pointed out long before they were actually used in airplanes because they became economically practical only when high-speed planes made them increasingly desirable and thick cantilever wings made them possible.

There Are Four Types of Monoplanes.

The four types of monoplanes differ in the point where the wings are attached to the body (fuselage). In the parasol type, the wings are above the fuselage.

The high-wing type of monoplane has its wings at the top of the fuselage.

The mid-wing type of monoplane is uncommon, and the low-wing type of monoplane is best adapted to military service and commercial use where upward vision is an important factor.

Biplanes offer some advantages in maneuverability, but their external bracing offers too much drag for high speeds.

There are certain definite reasons for each type of airplane design such as speed, high rate of climb, stability, maneuverability, range, and capacity.

Rotary-wing Airplanes Make Possible a Direct Take-off.

The autogiro and the helicopter are typical examples of rotary-wing airplanes.

An interesting feature of some autogiros is that the blades may be folded back over the horizontal tail surfaces of the machine while on the ground, thus permitting the machine to be driven down a highway and also reducing the hangar space required.

FIG. 150. The autogiro. (Courtesy of Science Service.)

The helicopter can go forward, backward, or sidewise. It can stand still in the air. It can land so gently that the wheels will not move more than a very short distance after touching the ground.

The helicopter differs from the autogiro in that it has no regular propeller but depends upon tilting the rotor for forward or backward motion.

The modern autogiro has a rotating wing; it depends upon its whirling blades to keep it in the air; these blades operate even when the engine fails, to permit a safe landing. The autogiro has a propeller which gives it a forward speed of 125 miles per hour.

One future application of rotary-wing airplanes, for which they are well adapted, is the ferrying of passengers from airports in the outskirts of metropolitan centers to landing areas on roofs in the centers of business districts.

Occasionally more time is consumed in traveling the few miles to and from airports in cities than in traveling by airplane between airports hundreds of miles apart.

The Development of Efficient, High-power Airplane Engines Has Helped to Make the Modern Airplane Possible.

Liquid-cooled engines, such as the compact Allison engine, offer a number of advantages under certain conditions.

1. The engine can maintain top speed longer because it is easier to cool.
2. Better streamlining made possible by placing the engine in the fuselage makes higher speeds possible.

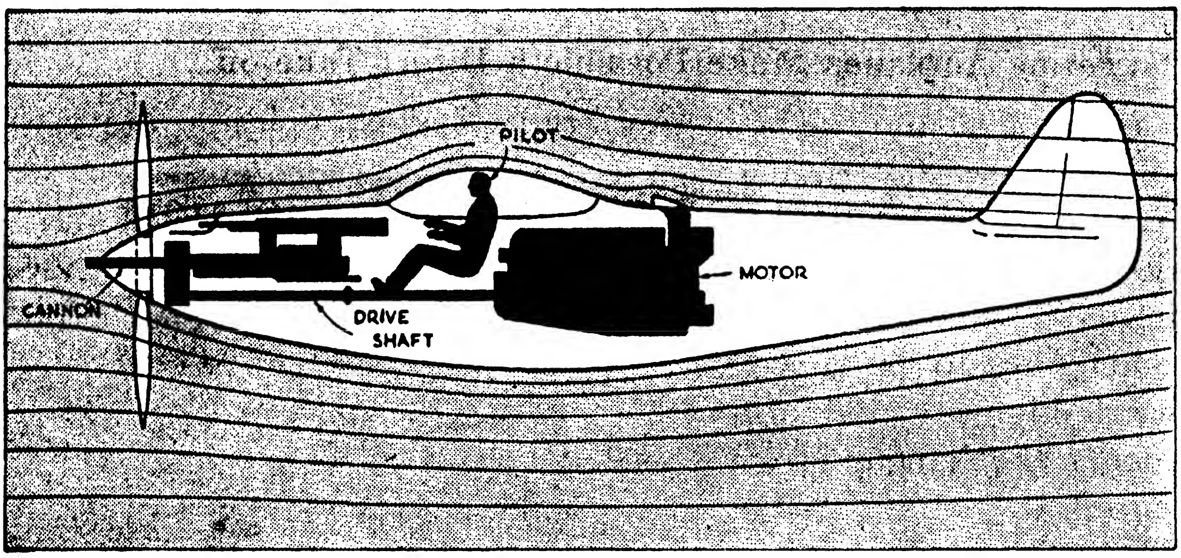


FIG. 151. How a liquid-cooled motor, separated from the propeller, permits streamline design for higher speeds. (Courtesy of *Popular Science.*)

On the other hand, improved designs of air-cooled engines and airplanes have resulted in streamlining approaching that so far obtained with water-cooled engines, so that in 1941 there appeared to be little choice between air-cooled and liquid-cooled engines in so far as speed is concerned.

The Liberty engine used water for cooling, but the Allison engine uses ethylene glycol.

Airplane engines have the same working parts found in automobile engines, but there must be more precision in manufacture, and they have to be given better care.

Nearly every automobile driver has been guilty of driving an automobile immediately after starting a cold engine. Many automobile drivers regularly accelerate their engines while they are cold to warm them up quickly. Much of the wear in an engine is caused by running the engine at a high rate of speed before the oil has warmed up enough to lubricate it properly.

Experienced airplane pilots never start a flight with a cold engine or "race" it to "warm it up." The engine must be running at nearly the normal temperature before it is speeded up. One reason why airplane engines have to be thoroughly warmed up before taking off is

that they are about equally loaded at all times, while an automobile engine may be started with the clutch disengaged and then started in low gear to prevent overloading while cold.

Certain airplane-engine parts are not fitted as closely as in automobiles because more room must be left for the circulation of oil which lubricates the engine and to some degree cools it.

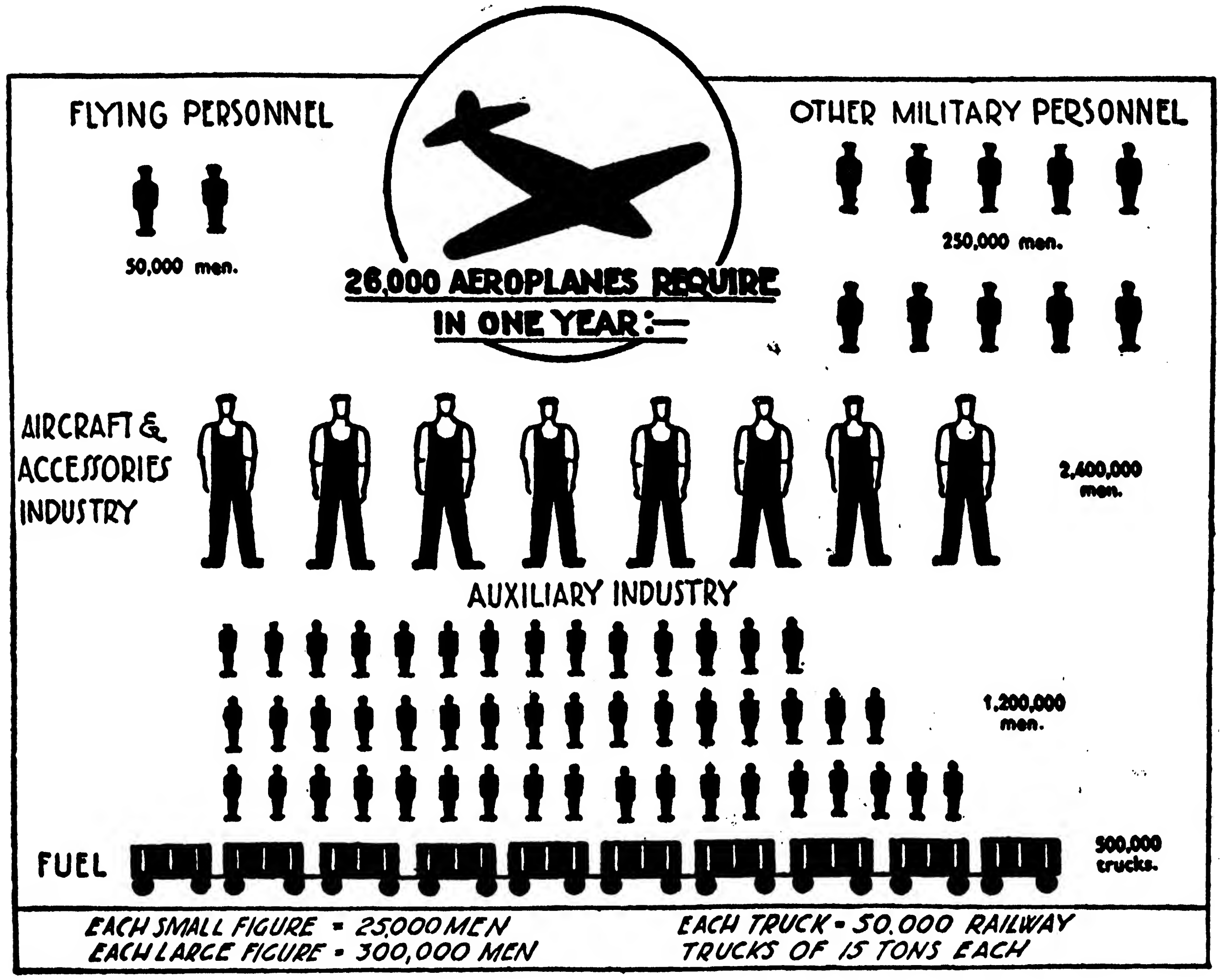


FIG. 152. From such charts one gains a clearer understanding of why war forces enormous costs upon nations. This chart appeared originally in the April 5, 1940 issue of *The Aeroplane*, London, and was reprinted in July by *Mechanical Engineering.* We are indebted to the latter for the privilege of reproduction here.

The density of air at an altitude of 21,000 feet is only half that at sea level; consequently the power of an engine falls off rapidly with an increase in altitude because less fuel can be burned by the same volume of rarefied air. This difficulty is compensated for by the use of a compressor (supercharger) run by the engine, which supplies air to the engine at pressures approaching the pressure of the atmosphere at sea level. The air is heated due to compression and turbulence within the supercharger, and it should, therefore, be cooled before it enters the engine.

Much more of the power of an engine is used in overcoming the force of gravity when climbing than is used to maintain a given altitude during flight, just as is true of climbing mountains with an automobile. Higher speeds are possible at high altitudes partly because the air has less resistance due to its lower density at higher altitudes.

New advances in petroleum technology have not only made available large quantities of gasoline of 100 octane number or higher, thus considerably increasing the potential power of airplane engines designed to use such fuels, but they have also made possible a high-octane-number fuel no more volatile than kerosene with a flash point (temperature at which the vapors will ignite) above 100° F. in contrast with flash points below room temperature for gasolines. Such fuels would be much safer to use, but their use would require that the fuel be injected into the engine as in the Diesel engine rather than be mixed with air in a carburetor.

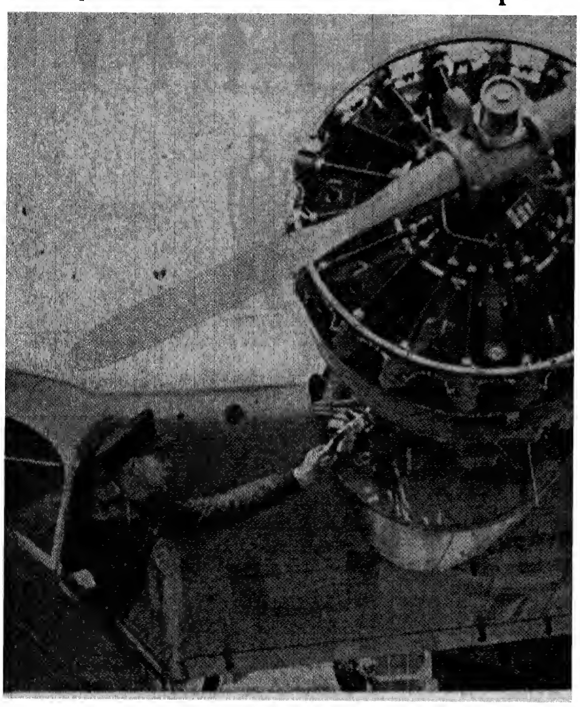


FIG. 153. Starting an airplane engine by means of a cartridge. (Photograph by Rudy Arnold.)

Diesel engines have already competed successfully with air-cooled gasoline engines for use in airplanes. Perhaps the airplane engine of the future will represent a compromise between the gasoline engine and the Diesel engine. The maintenance of Diesel engines is more costly than that of gasoline engines, and for that reason Diesel airplane engines have not been developed in the United States, where gasoline is plentiful.

Aeronautical engineers predict that engines of 5000 horsepower, liquid-cooled, of 24 or more cylinders, may be developed within the decade 1940–1950.

Many planes are now equipped with self-starters consisting of explosive cartridges that fire a charge of gas into the motor.

Another starter used for light planes is the hydraulic type of engine-starter, which uses oil compressed by a hand pump in the plane cabin.

Plastics Have Made Many Contributions to Modern Airplanes.

There has been a gradual change from the wire sticks and fabrics used to construct the first airplanes through the use of stainless steel and aluminum to the use of plastics and plywood.

Experimental airplanes have demonstrated that the wings and fuselage may be molded in large quantities at low cost from plastics laminated with plywood. The strength for a given weight of such plastic materials exceeds by ten times that of stainless steel in local buckling, but not in tensile strength.

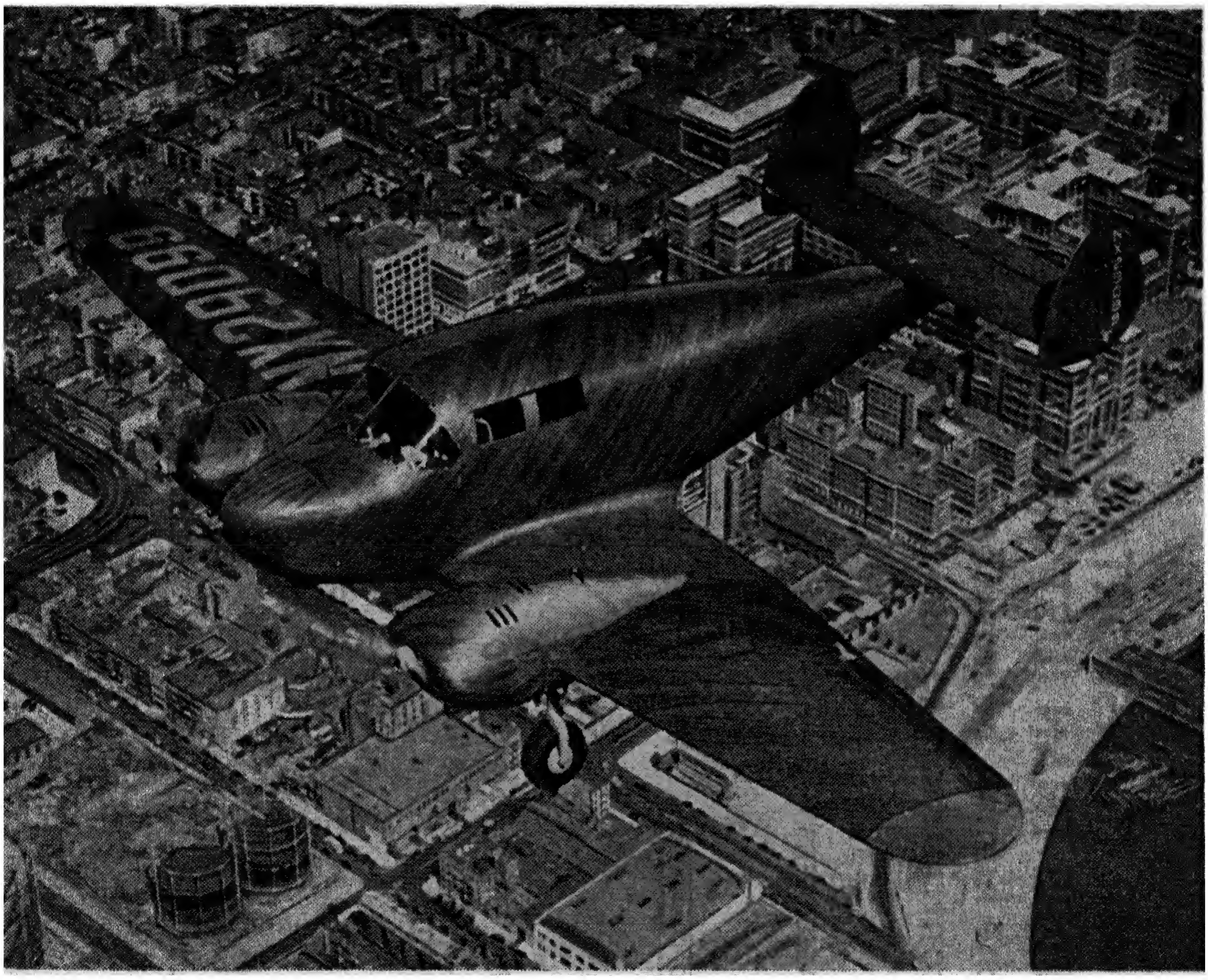


FIG. 154. Plastic-plywood plane. (Courtesy of the Langley Aviation Corporation.)

The surface of such planes may be made very smooth, thus reducing skin friction. Plastic surfaces are resistant to weather, impervious to water, reasonably fireproof, and corrosion-proof.

Plastics enter modern aircraft in many minor ways, such as in their use for instrument cases. Windows are sometimes made of acrylic resin sheets.

Neoprene Gasoline Tanks Have Many Advantages.

Neoprene-rubber gasoline tanks, called Mareng cells, have the following advantages:

1. They eliminate corrosion.
2. They are not affected by vibration or the surging of the gasoline in them.

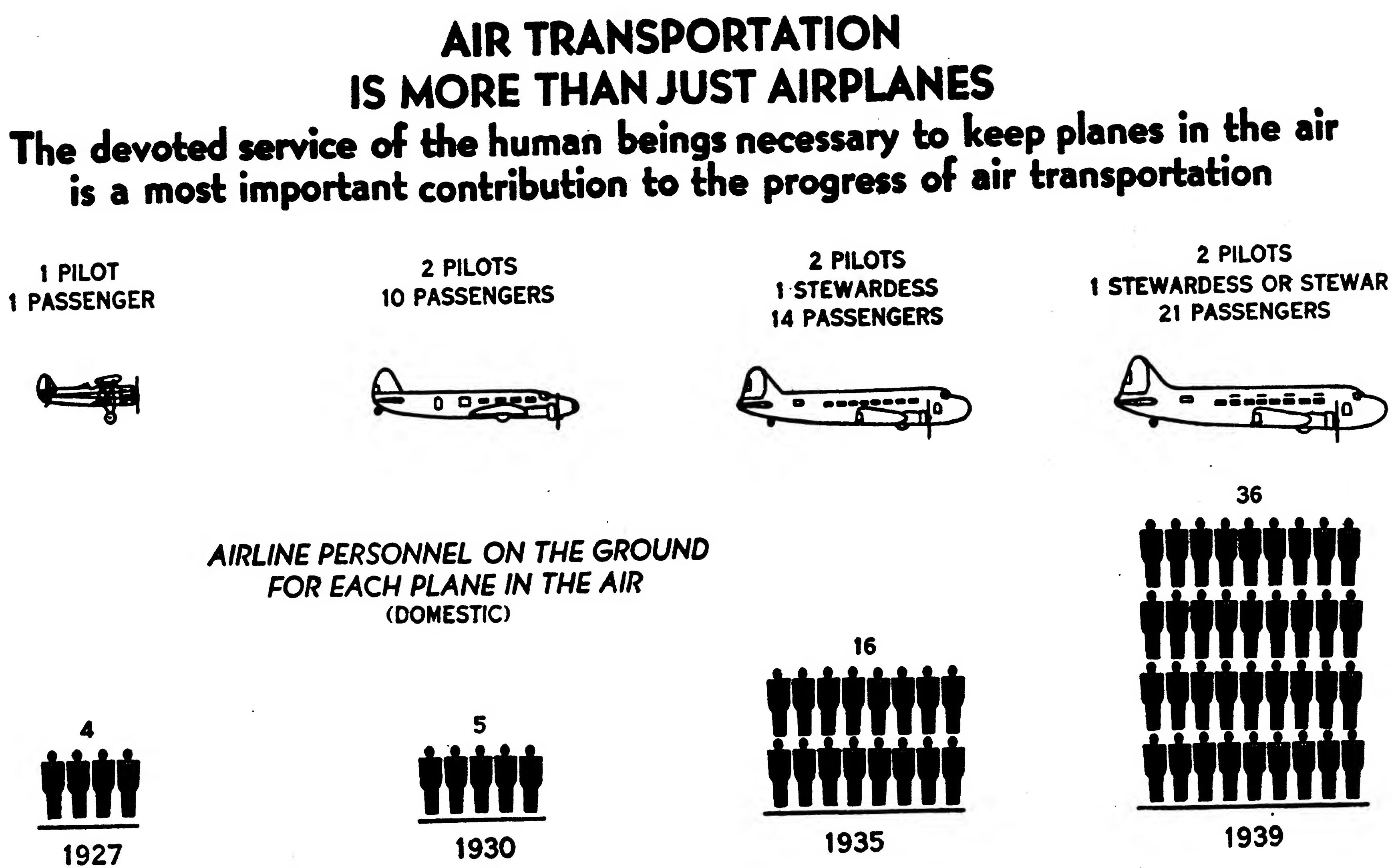

AIR TRANSPORTATION
IS MORE THAN JUST AIRPLANES
The devoted service of the human beings necessary to keep planes in the air
is a most important contribution to the progress of air transportation
1 PILOT
1 PASSENGER
2 PILOTS
10 PASSENGERS
2 PILOTS
1 STEWARDESS
14 PASSENGERS
2 PILOTS
1 STEWARDESS OR STEWAR
21 PASSENGERS
AIRLINE PERSONNEL ON THE GROUND
FOR EACH PLANE IN THE AIR
(DOMESTIC)
4
1927
5
1930
16
1935
36
1939

FIG. 155.

3. They can be easily repaired in the same way that automobile-tire inner tubes are patched.
4. They permit easy removal and replacement.
5. They are self-sealing after puncturing by bullets.

The "Caterpillar Club" Is a Very Exclusive Organization.

In the spring of 1918 a German flier was saved by a parachute — he was the first man to be saved by the use of a parachute. In 1924, ten men joined the newly formed Caterpillar Club, the only membership requirement being that one's life had been saved by a parachute. By 1929 there were two hundred members, Charles Lindbergh having established the record of four successful emergency parachute jumps.

In 1927 parachutes became standard equipment for civilian pilots engaged in commercial aviation.

The United States Government requires that every parachute be inspected and repacked every sixty days by certificated parachute riggers.

The improvements in modern planes have made them so safe that the Caterpillar Club is becoming more and more exclusive.

The rate of descent with a parachute is 16 to 20 feet per second, giving an impact equivalent to that experienced when jumping from a height of 8 feet. A normal parachute landing requires a height above the ground of not less than 123 feet.

Parachutes are used regularly to lower cargo from nonstop express planes and to lower supplies to fire-fighters.

Airplane Transportation May Soon Be the Cheapest Form of Transportation.

In 1939 the total cost of an airplane round trip from Atlanta to New York was only \$81.24, while the same round trip by train was \$58.75 for fare and about \$11.00 for meals and tips. The airplane trip required 12 hours and the train trip required 45 hours.

STUDY QUESTIONS

1. What is the possible result of racing a cold airplane engine to warm it up?
2. Why are cylinder clearances larger in aircraft engines than in automobile engines?
3. What are the advantages and disadvantages of airplane transportation?
4. What problems has the development of the airplane brought about or accentuated?
5. Prepare a brief outline of the history of aviation, selecting ten of the most important events listed in this Section and pointing out in each case why you considered this event to be important enough to be selected.

6. What is the real significance of the various records which pilots have made?
7. Prepare a brief summary of the advances made by aviation since 1940, obtaining your material from the current literature.
8. Why is there such a lag between fundamental research and its practical application?
9. Discuss the relative merits of biplanes and monoplanes.
10. What are the advantages and disadvantages of rotary-wing airplanes?
11. In what respects have the huge expenditures on military aviation benefited civil aviation?
12. What are the possible advantages of liquid-cooled engines as compared with air-cooled engines? What type of engine is preferred today, and why?
13. Why should automobile engines be warmed up before starting the automobile?
14. What are airplane-engine superchargers, and what is their purpose?
15. What are the advantages and disadvantages of high-altitude flying?
16. Discuss the contribution of plastics to modern airplanes.
17. What are the advantages of neoprene gasoline tanks?
18. How may one become a member of the "Caterpillar Club"?
19. Discuss the various applications of parachutes.

UNIT V

SECTION 8

FLYING AN AIRPLANE CONSISTS OF PROPERLY CONTROLLING THE FORCES OF THRUST, DRAG, LIFT, AND GRAVITY

Introduction.

Aerodynamics is the study of the forces produced by the relative motion between the air and a solid body. An airplane is a mechanically driven heavier-than-air craft, fitted with wings which support it in flight by the dynamic action of the air which results from the forward motion of the airplane relative to the air. The forward motion of the airplane is the result of a force, called the thrust, which is produced by the airplane propeller.

The dynamic action of the air resulting from the forward motion of the airplane may be resolved into two forces, the lift and the drag. The force of gravity is a static force, *i.e.*, it acts without any motion of the airplane.

It is the purpose of this Section to study how the forces of thrust, drag, lift, and gravity are controlled so as to enable one to fly.

The Thrust Is the Force Which Propels the Airplane.

Birds use their wings to attain forward motion in the air as well as to maintain their position in the air. In the airplane these functions are separated; and the propeller, which is really a specialized wing, is used to maintain forward motion. In the helicopter, however, the propeller has the dual action of the wings of a bird.

The propeller produces the force called the thrust in accordance with Newton's third law of motion, which states that *to every action there is always an equal and opposite reaction.*

A rocket is propelled through the air by the thrust which the escaping jet of gases produces against the rocket. The backward force of a propeller against the air is what forces it forward. The propeller may be placed in front of the engine or behind it. In the first case the airplane is called a *tractor*, and in the second case it is called a *pusher*.

An airplane propeller acts like a boat propeller, but it has to be much larger relative to the size of the ship because the density of the air is much less than the density of water. Propellers act like wood screws, bits, or augers, in the way in which they force their way through matter.

The denser the air is, the greater will be the forward motion produced by a revolution of the propeller, because a greater mass of material has to be moved by the propeller and therefore a greater force is exerted.

Take-offs require longer runs, and the rate of climbing is lower on damp days than on dry days, because the density of damp air is less than that of dry air.

Metal propellers are more efficient than wood propellers because of their thinner sections. A change from a wood to a metal propeller may result in an increase of air speed (speed of the airplane relative to air) as high as 5 per cent.

The pitch of a propeller determines the distance which the propeller advances per revolution. It is important that all portions of the propeller have equal pitch, and for that reason the propeller is so designed that it has increasingly greater angles toward the hub (center), so that each portion of the blade will perform an equal share of the propelling action. Inasmuch as the blade travels faster at the tip than at the hub the blade is tapered.

When taking off and climbing, the pitch of the propeller should be least, thus obtaining maximum power by allowing the number of revolutions per minute of the engine to increase; but when flying at a cruising-altitude, the propeller pitch should be increased in order to permit it to take the maximum "bites" out of the air. The maximum amount of power is required when taking off and climbing. When flying at a level, the highest efficiency is obtained by maintaining the manufacturer's recommended number of revolutions per minute by increasing the pitch of the propeller. Large, high-speed airplanes have devices by which the propeller pitch may be varied automatically so as to keep the number of revolutions per second constant. This is of special importance in multi-engined aircraft, as it is a means of keeping the engines accurately synchronized.

The Force of Gravity Must Be Considered in Designing an Airplane.

The performance of an airplane depends upon the power and the weight of the airplane. The speed of an airplane is not greatly increased by increasing the power of the engine because the horsepower varies as the cube of the speed — doubling the speed requires eight times as many horsepower.

Weight, *i.e.*, a measure of the force of gravity, has a pronounced effect on the performance of an airplane, as would be expected; and designers go to great lengths to obtain light materials of great strength and to design structures of great strength for the weight of materials used.

In World War II German aviators towed strings of five gliders having long slender fuselages and tremendous wings, by means of large transport planes. Each glider was said to be capable of carrying fifteen to twenty men. These gliders were used in the attack on the island of Crete. The gliders acted as the equivalent of a very greatly increased wing area for the transport planes, giving them much greater lifting power. Such a train of planes would naturally have to sacrifice speed for lifting power.

The Drag Opposes the Thrust.

The drag is the resistance of the motion of the airplane relative to the air. The drag is the result of the displacing of air masses, surface friction, and turbulence. Turbulence is the irregular motion of the atmosphere produced when air flows over an uneven surface.

That portion of the frictional drag which is produced by nonlifting surfaces is called the *parasitic drag*. The drag of the aircraft is determined by computing the equivalent flat-plate area of the wing and other parts of the aircraft.

The drag is decreased by streamlining. Landing gears are made retractable in large planes so as to reduce the drag. The earlier airplanes had most of their struts and braces exposed, but modern planes enclose these within the airfoils in order to decrease the drag.

An important principle to keep in mind is that the drag increases with increased speeds just as the lift does, and for that reason streamlining is very important for high-speed airplanes. The greater the area of the airfoil is, the greater will be the drag. Inasmuch as the lifting power of an airfoil is increased by increasing the speed of an airplane, the tendency in modern airplane design is to decrease the wing area so as to decrease the drag and use more powerful engines so as to increase the speed, especially to give the airplane performance or climbing ability.

The same results are obtained by moving the air relative to the airplane that are accomplished when the airplane moves relative to the air. Wind tunnels enable engineers to test small-scale models and even full-scale airplanes. Lift and drag measurements made in wind tunnels enable engineers to calculate the number of feet of wing area required to support an airplane of a given weight carrying a maximum load at a given speed.

The drag increases with increases in the angle of attack, until at the *burble point* (the angle of attack at which the air no longer flows smoothly over the airfoil) the airplane stalls, *i.e.*, it ceases to maintain altitude because the lift has been destroyed.

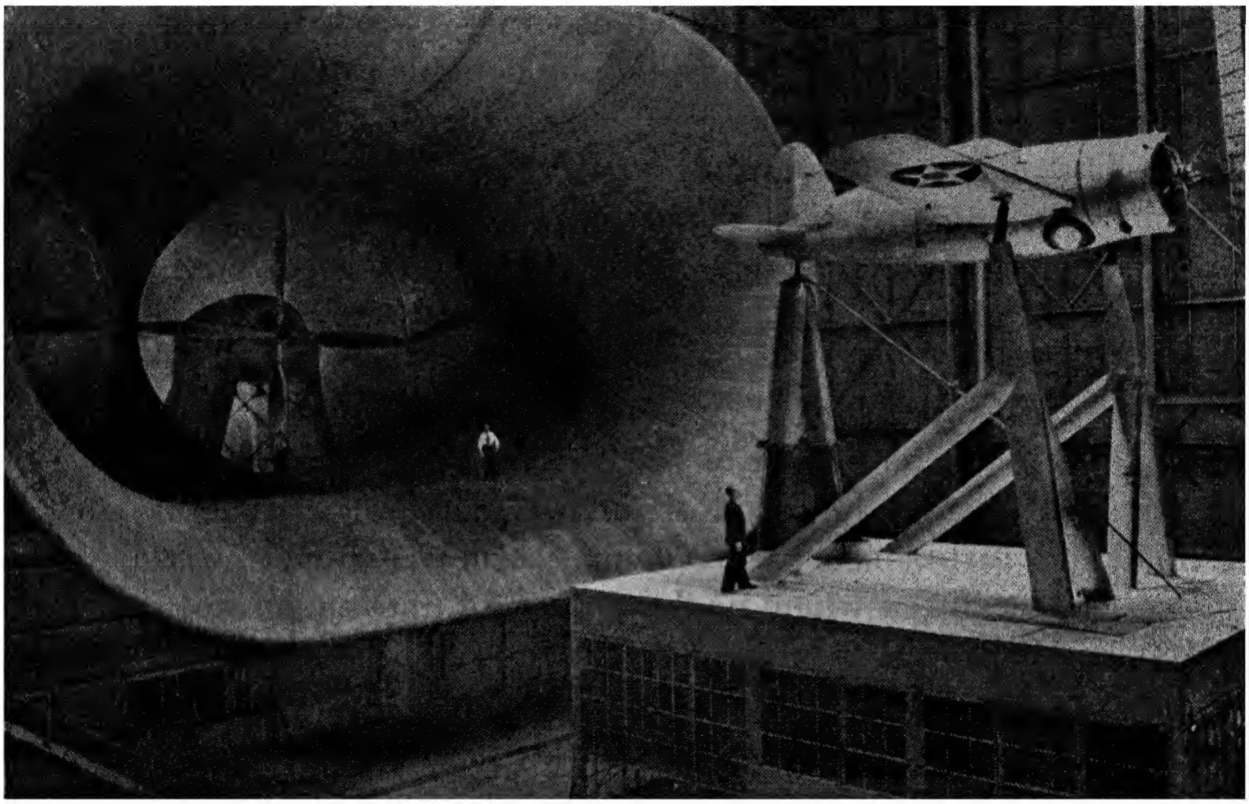


FIG. 156. National Advisory Committee for Aeronautics full-scale wind tunnel, Langley Field, Va. The Brewster XF2A–1 airplane mounted for test in the full-scale tunnel, the largest wind tunnel in the world. The airplane is supported in the jet on struts which transmit the forces to balances in the house below. Streamline fairings around the struts shield them from the air stream to eliminate extraneous forces that would not act on the airplane in flight. The air stream in this tunnel is 60 feet wide and 30 feet deep. Two 35½ foot propellers, operated by 4000-horsepower electric motors, produce a wind of 118 miles per hour past the airplane. (Courtesy of the National Advisory Committee for Aeronautics.)

The greater the camber (*i.e.*, curvature), the greater will be the drag. Inasmuch as the lifting power is also increased by increasing the camber, the airplane-designer is forced to compromise depending on whether he wishes high speed or high lift characteristics.

The Lift of an Airplane Is an Application of Bernoulli's Principle.

A Venturi tube is a short tube of small diameter with large openings in the front and the rear. The flow of air through the Venturi tube causes the pressure to drop in the tube in proportion to the velocity of the flow of air.

The Venturi tube is an application of *Bernoulli's principle*, which states that *when the rate of flow of gases or liquids is increased the pressure decreases.* Venturi tubes increase the rate of flow of a gas or liquid under a given pressure in the constricted portion of the tube.

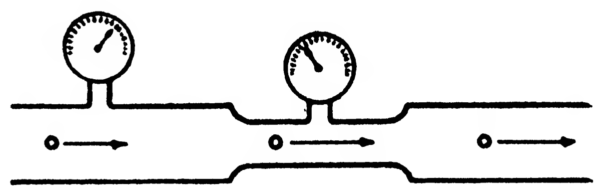


FIG. 157. Bernoulli's principle. The pressure is reduced at the constricted portion of the pipe.

The gauges shown in the Venturi tube in Fig. 157 can be graduated so as to show rates of flow of liquids or gases through the Venturi tube. Meters can even show the amount of water used in any given time. Such meters are called Venturi meters.

Figure 158 shows one type of Venturi "Pitot tube" used with the air-speed indicator of an airplane. The two open ends of the Venturi "Pitot tube" are mounted in the airplane so as to face the direction to which the airplane is pointed. The difference in pressure on the two sides of the air-speed indicator varies with the air speed; the instrument may be graduated to read in terms of miles per hour.

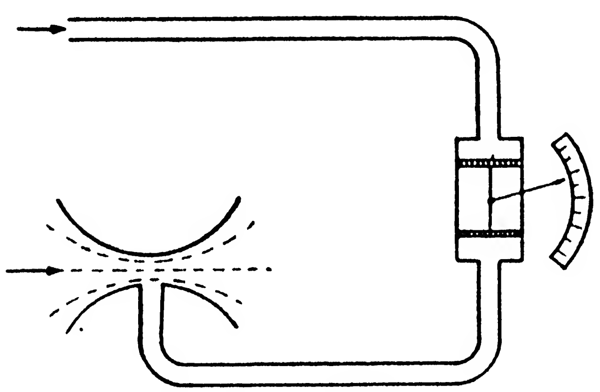


FIG. 158. Principle of the air-speed indicator, an application of Bernoulli's principle.

Figure 159 shows how the streamlining of the wing causes the air above the wing to travel faster than the air below the wing. The increase in the velocity of the air above the wing thus decreases the pressure above the wing, and the decrease in the velocity of the air below the wing increases the pressure below the wing. This combination of low and high pressures produces a pull and push on the wing which is called the *lift.* From 65 to 100 per cent of the lift is due to the low pressure above the airfoil, depending upon the angle of attack.

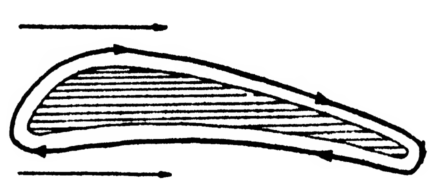


FIG. 159. The circulatory stream of air about the wing of an airplane, which combined with the sweep of the air from left to right yields a velocity of air above the wing which is greater than that below.

Bernoulli's Principle Has Many Other Interesting and Practical Applications.

A "cut" tennis ball, a "sliced" golf ball, or a "curved" baseball given a spin when pitched will follow a curved path because the rota-

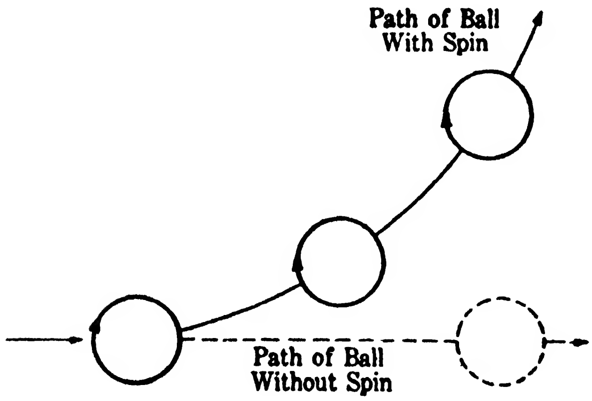


FIG. 160. The path of a baseball is curved by the spin given the ball by the pitcher.

tion of the balls piles up air on one side and reduces the pressure on the other side, as shown in Fig. 161. The path of the ball is therefore deflected toward the direction of least pressure.

A ping-pong ball will be supported in an air stream or a jet of water, as shown in Fig. 162, and is prevented from falling off the jet.

Figure 163 shows how a card with a pin projecting up into the hole in a spool is held near the spool when air is blown through the spool, because the velocity of

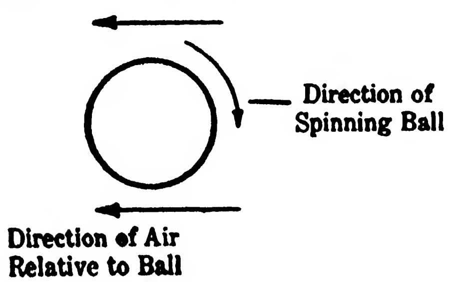
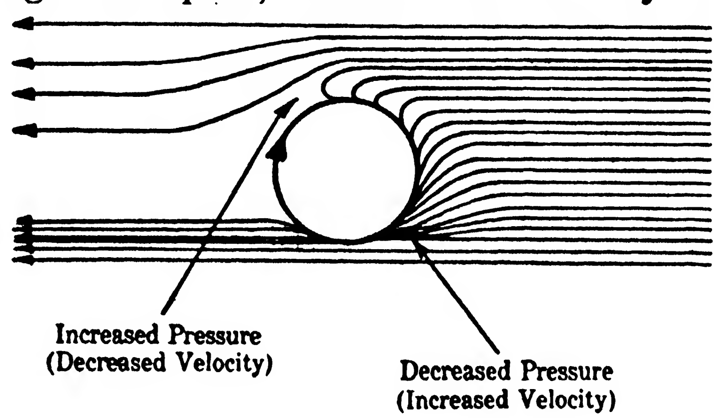


FIG. 161. Bernoulli's principle applied to a "curved" baseball.



the air is increased and therefore the pressure is decreased above the card to a value lower than the atmospheric pressure below it.

The same principle is applied in the automobile carburetor, where a stream of air flows through a narrow passage and thus sucks in gasoline from the jets and mixes with it.

The steam-injector, used in forcing water into boilers at high pressures, is based on this same principle.

Two ships at anchor near each other in a river current or tide or two ships moving through the water side by side may be drawn together in the same way that the tennis balls hung near each other by long threads will be drawn together when a jet of air is blown between them.

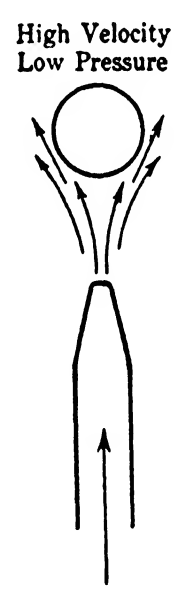


FIG. 162. A ball supported on a blast of air. — An illustration of Bernoulli's principle.

The Lift Opposes the Force of Gravity.

The force which lifts the airplane from the earth and sustains it while in flight is called the *lift.*

An airfoil is any surface which when moved relative to the air gives a useful dynamic action. The wings, ailerons, vertical tail fin, rudder, stabilizer, and elevators of an airplane are all airfoils because they give a useful dynamic action.

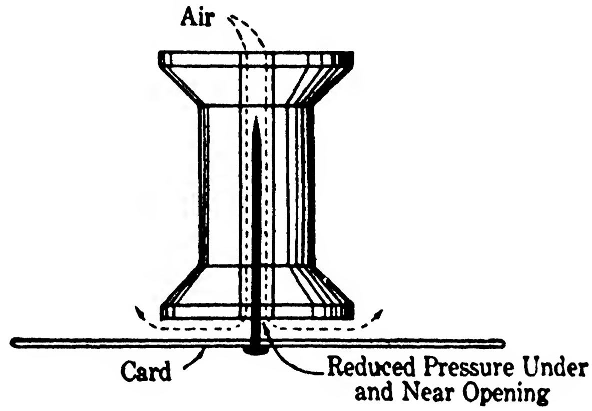


FIG. 163. Why a card is held against a spool when one blows through the spool against the card. The pin keeps the card from slipping sidewise.

The main airfoils which produce the lift are the wings.

The lift of an airfoil depends upon four factors: (1) the angle of attack, *i.e.*, the angle at which the wing meets the air; (2) the density of the air; (3) the speed of the plane relative to the air; and (4) the design or shape of the airfoil.

Lift increases as the angle of attack increases up to a certain point. Lift also increases with an increase in the density of the air and as the square of the speed of the airplane. If the speed is doubled, the lift is increased four times.

In taking off from the ground, the airplane has to attain a certain speed before the lift is sufficient to overcome the force of gravity.

If the angle of attack exceeds what is called the *critical angle*, or *burble point*, the lift will decrease, and the airplane will *stall*.

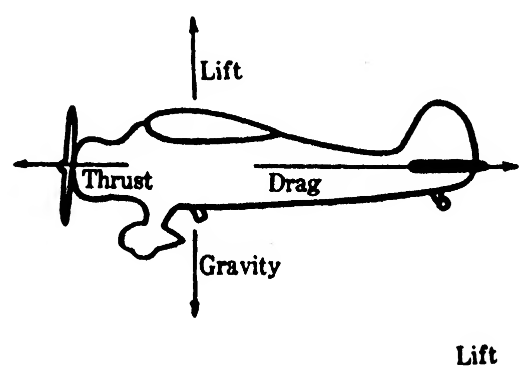


FIG. 164. The forces acting on an airplane in flight.

For an airplane of a given weight, the greater the wing area, the slower the airplane can fly without stalling. Wings are given a *camber* (curvature) to increase the lift, but in so doing the drag is increased and the speed is decreased.

The factors affecting the lift are best seen in the formula: weight equals the product of a constant [1] for the type of airfoil, the density of the air, the area of the wing, and the velocity squared. For an airplane of given weight any one of these four factors may be varied, provided that one other factor is varied to maintain the same total lift.

[1] These constants for every type of airfoil have been obtained by wind-tunnel tests.

Flaps and Slots Permit Landings with Smaller Wings Than Would Otherwise Be Possible.

In order to obtain a relatively low landing speed, a relatively large wing area is required, but such a large wing area causes too much drag at high speeds. Flaps on the trailing (rear) edge of a wing airfoil change the camber of an airfoil and thus give it the greater lifting power and slower speed required for landing.

Sometimes slots are provided in the leading edge of the wing airfoil. These slots make it possible to increase the angle of attack from 2° up to 30° or more without going into a stall and thus increase the lifting power of an airplane at slow speeds. When the airplane is nosed up into a high angle of attack, the air, instead of flowing over the leading edge, flows up through the slot and over the thick part of the wing, which gives the airfoil a high lift characteristic. Fixed slots, *i.e.*, those which remain open at all times, work automatically to prevent stalls. Some of the modern small airplanes are stall-proof.

The Direction of Flight of an Airplane Is Controlled by Such Airfoils as the Rudder, the Elevators, and the Ailerons.

There are three axes of motion of an aircraft — the vertical, the longitudinal, and the lateral — about which the airplane may be rotated, one, two, or all three at a time.

1. *The vertical axis.* Rotation about the Z-axis, called the *yaw*, changes the direction in which the nose is pointing from left to right and vice versa. Deflection of the tail rudder causes the airplane to turn just as that of the rudder on a boat turns the boat.

The plane is turned to the left or right by pushing on the rudder bars with the left or right foot, respectively.

2. *The longitudinal axis.* Rotation about the X-axis causes one wing to lift as the other wing is lowered, and the plane is said to *roll.* The rolling does for an airplane what banking a turn does for automobiles.

The airplane is caused to rotate about its longitudinal axis by moving the stick to either side; the airplane will roll in the same direction that the stick is moved.

The rolling of the airplane is controlled by the ailerons. The ailerons are identical to flaps in their action except that as one aileron moves down the one on the opposite wing moves up.

When making turns an airplane is banked in order to prevent skidding sidewise. If one overbanks the airplane, it will slip toward the center of turn. Thus when one wishes to make a right turn, the right rudder bar is pushed with the right foot and the stick is moved to the

right. After attaining the proper degree of bank, the stick is returned to neutral. Any lateral movement of the stick is only temporary, while banking the airplane or taking it out of bank.

3. *The lateral or transverse axis.* Rotation about the Y-axis produces what is called the *pitch*, *i.e.*, the motion in which the nose goes up or down.

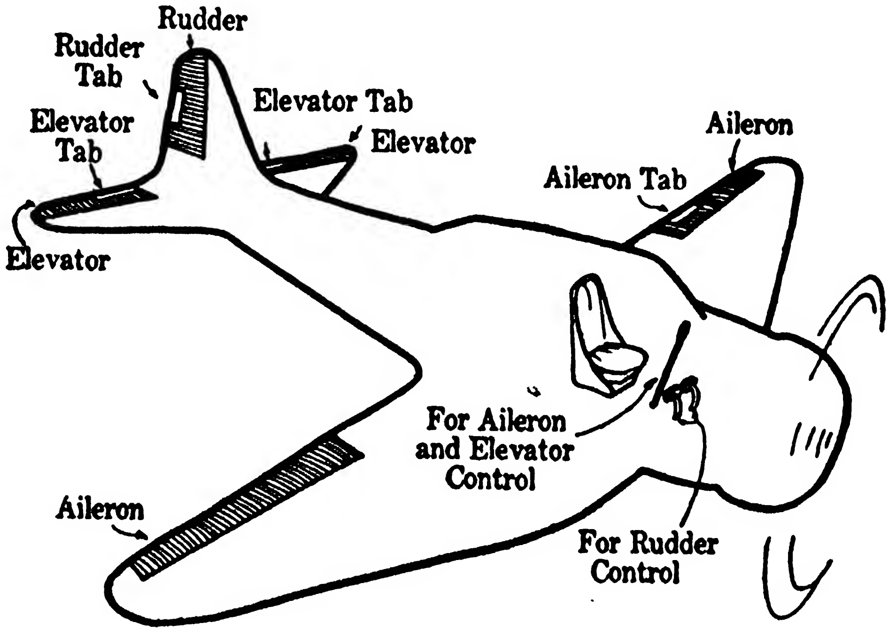


FIG. 165. How an airplane is controlled in flight.

When the stick is pulled back by the hand of the pilot it throws the rear elevators upward and thus forces the tail of the plane downward and the nose upward. Thus one pulls the stick toward him to ascend and pushes it away from him to descend.

The Vertical and the Horizontal Stabilizers Make Flying Easier.

The loading of an airplane may be such that it changes its center of gravity; the consumption of gasoline decreases the weight of the fuel, and the amount of freight and number of passengers also change the center of gravity. If the airplane flys nose-heavy, the pilot must exert a constant pull-back on the stick, or he must adjust the horizontal stabilizer to a position where the nose will neither be up nor down when the stick is released.

The action of the propeller on the air not only creates a backward thrust but also causes the swirling motion in the air which tends to yaw the plane by its action on the vertical tail surfaces. The vertical stabilizer is adjusted to overcome this force, by adjusting the trimming tab or offsetting the vertical fin.

Counterclockwise rotation of the plane produced by the torque (*i.e.*, the rotational force) due to the clockwise motion of the propeller is prevented by reducing the lift of the right wing and increasing the

lift of the left wing. When the angle of attack is increased to increase the lift of a wing, it is called "wash in"; when decreased, it is called "wash out."

When the left wing is "washed in" to increase the lift, offsetting engine torque, the projected area of that wing is also increased, causing the plane to yaw to its left. To correct this, the vertical stabilizer is offset slightly to the left.

Modern Airplanes Are Quite Stable.

The ability of an airplane to return to its original normal position without effort on the part of the pilot or with the controls released is

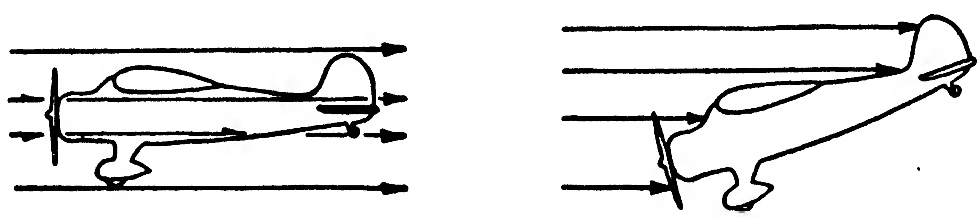


FIG. 166. When the airplane is disturbed longitudinally, *i.e.*, when the nose is pulled up, the airplane loses speed because the downward force on the horizontal tail surface decreases and the tail comes up, placing the airplane in a diving attitude. As the speed increases in the dive, the negative lift increases on the tail, forcing it downward and placing the aircraft again in level flight attitude.

called positive stability. Many modern airplanes will practically fly themselves; they will recover from a dive or climb, a bank or a turn with the controls released. The stability of an airplane is accomplished by proper design features. *These are the features built into the aircraft which give it stability.*

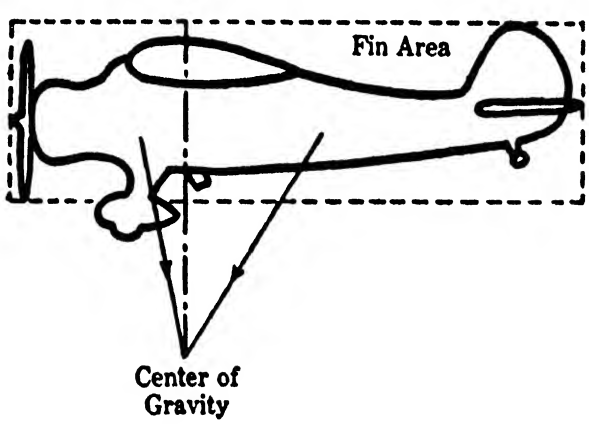


FIG. 167. When the airplane is disturbed directionally it will assume the new course, but it will not continue to turn because the vertical airfoil behind the center of gravity is greater than that ahead of the center of gravity.

When a wing is dropped, it automatically comes back up again because there is an additional lift on the low wing.

When the airplane is disturbed longitudinally, *i.e.*, when the nose is pulled up, the airplane loses speed, and the tail comes up, thus placing the aircraft again in level-flight attitude.

When the airplane is disturbed directionally, it will assume the new course but not continue to turn. This is due to the fact that there is a greater amount of fin area back of the center of gravity than in front of it.

An Airplane Practically Flies Itself.

It is said that a well-trained pilot is four times as safe flying in an airplane as he would be in driving an automobile but that a poorly trained pilot is four times as safe in an automobile as he would be in an airplane. The student pilot has a tendency to use brute strength and violent manipulation of the controls when an airplane goes into an unexpected motion, and in his excitement he may do the wrong thing.

A safe rule is to leave the controls alone and let the airplane return to its normal position by itself, provided that there is sufficient altitude. The majority of airplane accidents are caused by flying so close to the ground that there is not time for the airplane to return to a normal position if something unexpected happens.

A poor automobile driver is constantly turning the steering wheel back and forth and manipulating the brakes; a poor pilot likewise trys to do too much of the work which the airplane is designed to do for him.

An airplane will not fall just because the engine fails. Gliders often remain in the air for many hours, and the heavier airplanes can glide for some time in search of a landing field, provided that the original altitude above the ground was high enough.

There are no such things as air pockets, and up- and down-currents of air are not serious except when flying too close to the ground or when the air currents are very powerful, as in thunderstorms or in mountainous country. Bumpy air does no more harm to an airplane than a rough sea does to a ship.

STUDY QUESTIONS

1. What is an airplane?
2. What causes the dynamic action of the air upon an airplane?
3. How is the effect of propeller torque counteracted in the rigging (adjustment) of an airplane?
4. How could left-wing heaviness be corrected?
5. Why is the vertical fin often offset slightly?
6. What are the probable causes of nose-heaviness, and how may nose-heaviness be corrected?
7. What is parasite resistance?
8. Of what use is an adjustable stabilizer? What substitutes for adjustable stabilizer do some airplanes have?
9. What is an airfoil?
10. List the airfoils of an airplane and mention the useful purpose of each.
11. What are the four forces which act on an airfoil?
12. What is the angle of attack?
13. In flying out of a small field, which would be preferred, a small pitch or a large pitch for the propeller?

14. What causes an airplane to stall?
15. What factors most affect the speed of an airplane?
16. What are the advantages of cambered wings over flat wings? What factors determine the maximum amount of camber that can be used?
17. What is meant by the term *camber?*
18. Explain the thrust produced by the propeller.
19. Explain the lift of an airplane.
20. Name the three axes of an airplane and describe the controls which the pilot uses to determine the rotation about each axis.
21. What would a pilot have to do to make a left turn?
22. Name the airfoils which give control to each axis.
23. Why should an airplane always be taken off into the wind?
24. Why should an airplane be landed against the wind?
25. Name three ways of correcting nose-heaviness.
26. Why is streamlining so important, especially at high speeds?
27. What are the advantages of metal propellers over wood propellers?
28. What is a tractor airplane?
29. What forces oppose the forces of gravity and thrust in an airplane in flight?
30. State Newton's third law of motion and apply it to airplane flight.
31. What factors determine the lift of an airplane?
32. What is meant by the *burble point?*
33. What is meant by the *stability* of an airplane?
34. Mention several important safety rules for student pilots to keep in mind.

UNIT V

SECTION 9

AVIGATION IS THE SCIENCE OF CONDUCTING AN AIRCRAFT FROM A POINT OF DEPARTURE TO THE DESTINATION

Introduction.

The science of directing an aircraft from *here* to *there* is much different from that of traveling over well-marked highways by automobile. Familiar landmarks do not look the same from an airplane as they do from the ground. In bad weather and at night even familiar landmarks are often lost to view. When one has once learned to fly, only half the battle has been won. The next problem is that of learning how to navigate an aircraft. The navigation of an aircraft is often spoken of as avigation to distinguish it from the navigation of watercraft.

There are four recognized methods of navigating aircraft: (1) navigation by celestial observation, (2) navigation by terrestrial observation (pilotage), (3) navigation by dead reckoning, and (4) navigation by use of the radio beam.

1. Navigation by Celestial Observation Depends upon the Frequent Determination of the Position of an Airplane by Observation of the Sun or Stars.

Navigation by celestial observation is the most advanced and most scientific of all of the methods, but it can be used only when the sun or selected stars are visible and thus permit the determination of their angle of elevation with the sextant. The observations and computations require more attention than a pilot can spare, so that celestial navigation is only possible when a navigator can accompany the pilot.

Celestial navigation is practical either day or night provided one can fly above the clouds, and efficient operation demands that long flights be made at high altitudes. Celestial navigation is especially valuable for flying across oceans where there are no landmarks and when flying in the substratosphere above an overcast because often radio signals are affected unfavorably at these altitudes.

Celestial navigation is the same for both avigation and marine navigation, except that in avigation the observations and computations are made less accurately, due to the unsteady and more rapid motion of the airplane.

Celestial navigation involves the following steps:

1. Determine the angle of elevation of the sun or stars selected with the sextant.
2. Note the exact time of the observation.
3. Compute the line of position from the sextant observation and the time it was made.
4. Plot the line of position on a chart.
5. Determine a fix (*i.e.*, the position) by plotting a line of position from a second star.

The line of position is a short section of a circle drawn with the radius starting at a point directly under a given star at the time of observation, as obtained from an almanac, and extending a distance of 90° minus the angle of elevation above the horizon observed with the sextant. This section of the circle is drawn for a short distance near the position where the airplane is thought to be. The intersection of this circle with the line of position obtained from another celestial object gives the position of the airplane.

2. Navigation by Terrestrial Observation (Pilotage) Is Applicable Only over Familiar Terrain.

Terrestrial observation is applicable only for short flights over familiar terrain or well-marked airways. It is not economical to follow highways or railroads because they seldom take the shortest path between two points. A pilot who is depending upon terrestrial observation would be lost if night overtook him or the visibility should become poor, due to a sudden change in weather.

Terrestrial navigation has been made easier by the erection of airway beacon lights, which may be recognized and followed by night with the use of charts (maps) of the civil airways. By day, these beacon stations may be recognized by the large numbers painted on the power sheds. Airport hangars generally have large identification marks or names on them.

Detailed aeronautical charts, revised every five years or less, show the important topographical information of a region, such as rivers and lakes; the cultural features, such as cities, highways, and railroads; the relief, *i.e.*, the ridges, valleys, canyons, bluffs, and mountains with their altitudes; and such aeronautical data as airports, army fields, beacons, and radio stations.

Aeronautical charts are similar to relief maps in the manner in which they show differences in altitude. Relief is shown by contour lines, areas of equal altitude between the contour lines being shown in the same color, while areas of different altitude are shown in different colors. A contour represents an imaginary line on the ground, every point of which is at the same altitude. With a little practice one can easily read a contour map or chart. Figure 168 shows how a contour is constructed.

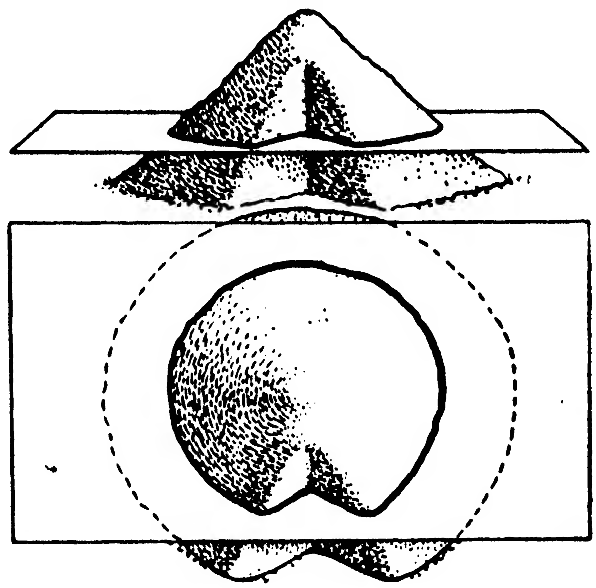


FIG. 168. How contour maps are made.

For cross-country flying the course is laid out on the chart and carefully studied by the pilot before taking off.

By 1941 the United States Government had over 25,000 miles of civil airways, with rotating beacons at intervals of about 15 miles and with intermediate or emergency landing fields at 50-mile intervals. Traffic is controlled by means of radio communication on these civil airways to avoid collisions.

3. Navigation by Dead Reckoning Depends upon the Use of Five Fundamental Instruments.

Navigation by dead reckoning depends upon the determination of positions by means of calculating their direction and distance from a known position, from the course, the direction, speed of the wind, and the cruising air speed. With the above information the ground speed and track are easily obtained by simple geometric plotting.

Dead reckoning is used when other methods of navigation are not possible, and it is usually quite accurate.

Five fundamental instruments are essential for navigation by dead reckoning.

(*1*) ***A clock or watch.***

(*2*) ***An altimeter.*** An altimeter is an aneroid barometer that registers atmospheric pressure on a scale which is calibrated to read in feet above sea level. The altimeter has to be set just before leaving the ground in accordance with the atmospheric pressure at that time and the altitude of the airport. Inasmuch as an increase in temperature causes air to expand, the altimeter will give readings which are too low to the extent of about 2 per cent for each 10° F. rise in temperature

above standard air 59° F. Sensitive altimeters are equipped with a setting device, which permits the pilot to correct the altimeter while in flight for any barometric pressure change which has occurred while he is in flight. A pilot may radio to the landing field and obtain the exact altimeter-setting for that field. His instrument then will read the exact altitude of the field above sea level when landing.

(*3*) ***The Magnetic Compass.*** The magnetic compass points in the direction of the earth's magnetic lines of force in any given location. The direction of the compass is caused to deviate by various magnetic attractions within the airplane. These deviations are reduced to a minimum by compensating magnets placed in the compass. The deviations of a compass vary according to the heading (the direction in which the airplane is pointed), so that a table of deviations at different headings must be prepared by actual observations.

Inasmuch as the earth's magnetic lines of force vary from a true north and south to a different extent at different locations, it is necessary to know the *magnetic variation*, *i.e.*, the angle between the true north and the magnetic north at any given location, in order to be able to determine the *true bearing*.

The directional gyro (gyro compass) contains a small gyroscope driven by suction from a venturi tube.

The gyroscope compass will maintain for a short time a direction to which it is set, but due to precession it changes direction at the rate of 3° every fifteen minutes and therefore has to be reset frequently. The directional gyro may be used as a turn indicator. Another instrument using the gyroscope is the *artificial horizon*, which enables the pilot to tell whether he is climbing or descending and whether his wings are level.

(*4*) ***The Air-speed Indicator.*** The air-speed indicator is an instrument that measures the air speed by measuring the pressure produced by the motion of the airplane relative to the air. The air-speed indicator is generally operated by a pitot tube, as described on page 369. The air-speed indicator reading decreases about 2 per cent for each 1000 feet of altitude, and air-speed corrections must also be made for temperature changes.

(*5*) ***The Drift Sight.*** Inasmuch as the velocity and direction of the wind change at different altitudes and at different times and places, wind direction and velocity must be observed while flying. The drift sight indicates the angular difference existing between the heading (the direction in which the airplane is pointed) and the track (the actual flight path of the airplane over the ground).

There are two basic problems in dead reckoning: (1) determine from

a chart the distance and compass heading to be followed between two points; (2) while in flight, determine and plot on the chart the track being made, on the basis of the observed compass heading, air speed, drift angle, and wind velocity.

The compass heading is the specific direction that the pilot will follow as read on his compass. The direction that the compass must point in order to enable the airplane to follow the intended track must be determined by correcting the true course (*i.e.*, the course as indicated by the angle between the true north and the direction of motion on the chart) for magnetic variation, compass deviation, and effect of wind.

While in flight the track being made may be calculated by reference to the compass heading, the approximate ground speed, and the elapsed time. This process is essentially just the reverse of the first problem. The drift angle enables the pilot to make the correction for wind.

When drift observations are impossible, because of adverse weather, the wind correction is calculated on the basis of wind velocity and direction given in weather reports.

Navigation by dead reckoning not only enables the pilot to fly under adverse conditions but also enables him to come close enough to outstanding landmarks shown on charts to recognize them and thus helps to keep the pilot from getting lost when flying by terrestial navigation. Radio navigation is likewise supplemented by dead reckoning.

Slightly more complicated methods of plotting permit a pilot to know how far he can go in a given direction under given wind conditions and return to his base or to an alternate base; also, he may intercept another plane in flight or a boat at sea and even leave and return to a moving base.

4. Radio Navigation Supplements Navigation by Dead Reckoning.

The radio aids navigation as follows:

(*1*) ***The radio enables the pilot to keep on his course.*** The radio range beacons situated on civil airways transmit radio signals which inform the pilot whether he is on or off the course, and if he is off the course which side he is on. The radio range system is regarded as an important aid to dead reckoning, but it is too much subject to static interference or mechanical failure to be depended upon as the only means of navigation.

(*2*) ***The radio enables the pilot to determine his position along the course.*** The radio direction-finder has a rotatable loop antenna and points toward a selected radio broadcasting station. The position of a plane on a radio range can be determined by locating the intersection

of the bearing of some off-course radio station with the radio range course or another radio station, thus obtaining a fix. The radio compass has a fixed loop; and so long as the pilot stays tuned to the station, his airplane is headed toward the station.

(*3*) ***The radio enables the pilot to make blind landings.*** By use of suitable transmitting devices at an airport and receiving devices, which control instruments in the plane, the pilot is enabled to follow a landing-beam with a high degree of precision.

(*4*) ***The radio altimeter tells the pilot how high he is above the ground.*** This information is frequently even more important than the height of the airplane above sea level as furnished by the aneroid type of altimeter.

(*5*) ***The radio keeps the pilot informed concerning weather conditions on his course.***

(*6*) ***The radio brings the pilot landing instructions at an airport and traffic instructions while on a civil airway.*** A recently developed instrument of much promise is the Flight-ray, which combines pictorially the readings of a gyro-horizon, directional gyro, altimeter, airspeed meter, radio compass, and radio landing-meter.

In 1940 there was announced an omnidirectional radio-range beacon which operates on ultra-high-frequency radio waves and thus minimizes the effect of static. It also permits the use of two-foot-high antennae instead of a group of 125-foot towers. The use of this beacon will enable the pilot to find his way to the beacon regardless of whether he is on his course or not.

The Civil Aeronautics Administration Has Contributed a Great Deal to the Safety of Flying in the United States.

The Civil Aeronautics Administration has not only established well-marked civil airways, traffic and airport control, and landing fields, provided meteorological service at airports and radio weather reports, prepared aeronautical charts and almanacs, erected beacon lights, and developed radio-range beams and other radio aids, but it has set up an excellent inspection service.

No airplanes are allowed to fly in civil airways or across state boundaries unless they are registered with the government and operated by licensed pilots. Airplanes are given frequent inspection. Student pilots are required to pass physical examinations; and they must also pass an examination in meteorology, aerodynamics, navigation, Civil Air Regulations, and service of aircraft, in order to obtain a private pilot's license which permits them to carry passengers. This license can be obtained only after the student pilot has passed flight tests. Flight

instructors and commercial pilots are required to pass more rigid physical examinations and more advanced theoretical and flight tests.

Passenger airplanes are required to have the following safety equipment in addition to the fundamental navigating instruments:

Tachometer — to measure number of revolutions per minute of the propeller.
Oil-pressure gauge — to be sure that the lubrication system is functioning properly.
Thermometers — to be sure that the engine is not too hot.
Manifold pressure gauge — to indicate horsepower output.
Fuel-quantity gauge.
Safety belts — to keep the passenger in his seat during flight.
Fire extinguisher.

Logbooks showing the number of hours of operation of the airplane and the engine between inspections are required to be kept.

For night-flying, a radio, a landing-light, landing-flares, forward position lights, and taillights are also required.

The numbers on airplanes are their license numbers, and the letters which precede them have the following significance:

N — Registered in the United States.
C — Suitable for passengers.
R — Suitable for certain industrial uses only
X — Experimental.
— — Airworthiness rating not established.

High-speed Flying Introduces Many Problems.

When flying a slow-climbing plane, a pilot breathes oxygen as he approaches higher altitudes, and the nitrogen is gradually taken out of the blood stream in respiration.

Modern high-speed airplanes can climb at the rate of a mile a minute. Due to the rapid reduction in atmospheric pressure, the nitrogen in the blood does not have time to escape, but forms bubbles which expand and produce aeroembolism — bends — which is identical with the bends of deep-sea divers. This difficulty may now be avoided by breathing a mixture of oxygen and helium while pedaling a stationary bicycle, in order to drive the nitrogen out of the body in preparation for a rapid ascent.

STUDY QUESTIONS

1. What are the five main instruments used in dead reckoning? What information does each instrument give? What are the corrections that have to be applied to these instruments?
2. Outline the two main problems of dead reckoning.

3. What aids does the radio make available to a pilot?
4. Define: (*a*) compass course, (*b*) true course, (*c*) compass heading, and (*d*) the track.
5. What aids are available for terrestrial navigation?
6. What is a relief map?
7. What is meant by a contour?
8. How are different altitudes shown on a relief map?
9. When in flight how would you check your ground speed over a given course?
10. How would you know whether or not the direction of the wind shifted while in flight?
11. Differentiate between ground speed and airspeed.
12. Compare the relative usefulness of the four types of avigation, indicating the conditions under which each one could be used to best advantage.
13. What aids does the radio make available for avigation?
14. What data are necessary for celestial observation? What are the sources of these data?
15. What information do aeronautical charts contain?
16. How are civil airways marked?
17. Does an air-speed indicator give a true reading at various altitudes?
18. What is a sextant?
19. What is dead reckoning?
20. What is meant by instrument flying?

UNIT VI

ENERGY MAY BE PROPAGATED THROUGH THE ETHER AND THROUGH MATTER BY MEANS OF VIBRATIONS

INTRODUCTION TO UNIT VI

This unit is devoted to the study of electromagnetic waves, which involve light and other vibrations ranging from cosmic rays to long radio waves. It also takes up the study of vibrations in matter, which constitute sound. In many respects, electromagnetic vibrations are similar to vibrations in matter, and for that reason they are studied in the same Unit. Both of these forms of energy differ so much from heat and mechanical energy, studied in Unit V, that it seemed best to study them in a separate Unit. Heat, of course, is a form of vibratory motion, for it will be recalled that heat has been defined as the vibration of molecules. The smaller units of matter which make up the molecules and atoms are likewise believed to vibrate; and, as we shall see, the electron, the unit of electricity, is considered to be a mere wave packet. It is quite proper, therefore, that the study of electricity in Unit VII be preceded by this study of electromagnetic vibrations and of vibrations in matter in the aggregate.

UNIT VI

SECTION 1

LIGHT IS A FORM OF RADIANT ENERGY

Introduction.

Few people ever become curious about the nature of light, but those who have become interested in the "why and how" of it have been richly repaid. It is now known that light is a form of radiant energy. Sometimes the term "light" is used in referring to all forms of radiant energy, but in a narrower sense it refers only to that portion of the electromagnetic spectrum of radiant energy to which the human eye is sensitive. The human eye sees but one octave of this vast scale of radiation. This visible octave is called light.

Light Is Wavelike in Nature.

The wavelike nature of radiant energy is easy to understand in this age of the radio. Nearly everyone knows that broadcasting stations set up disturbances which travel as waves whose lengths depend upon the transmitting apparatus. The sun may be considered to be a light-wave transmitter, and our eyes may be considered to be the receiving sets. The chief difference between radio waves and light waves is their frequency or the closeness with which they follow one another.

A study of water waves will help to illustrate the behavior of light. The water waves created in a shallow pan of water may be made visible by observing light reflected from the surface of the water onto a screen. If the pan is jarred, waves will be observed to start on opposite sides of the pan and pass through each other at the middle. When they reach the sides opposite to those from which they started, they will be observed to recoil.

This simple experiment illustrates two fundamental properties of wave motion: (1) two sets of waves can pass through each other without being altered; (2) waves can be reflected at the same angle that they are received.

Another property of light was probably observed in the second century by the Alexandrian, *Ptolemy*, who studied the refraction or bending of light rays as they passed from one medium to another.

Roger Bacon (1210–1292) studied the general phenomena of refraction and described the laws of reflection. In 1678 *Christian Huygens*, a Dutchman, developed the wave theory of light which was first suggested by *Leonardo da Vinci*. A few years later *Sir Isaac Newton* advanced a different theory. Newton's work on light and optics alone was sufficient to place his name on the roster of the world's greatest scientists. The Pythagoreans believed that light consisted of particles projected into the eye. Newton likewise believed that light must consist of a stream of corpuscles, for he could not account for sharp shadows in terms of wave motion. Water waves bend around obstacles and do not produce shadows. The same thing is true in the case of sound waves, except that the shorter wave lengths of sound will produce shadows. A hundred years after Newton it was shown that the extreme smallness of the wave lengths of light compared with the dimensions of the objects placed in their path explains the sharpness of the shadows produced. Strangely enough, the colored rings produced when light is passed through a polished glass plate in close contact with a lens of small curvature, called "Newton's rings," are now accepted as one of the best proofs of the wave theory of light.

It remained for *Thomas Young* (1773–1829) to revive Huygens' wave theory of light, which had been rejected for so long, largely on account of Newton's great prestige. In 1801 he concluded, as the result of studies in interference, that light was propagated in the form of waves rather than particles. Water waves show interference; thus, when two waves meet so that the crest of one coincides with the trough of another, they neutralize each other. When Young passed a narrow beam of light through two narrow slits in a screen, the rays from the two holes overlapped on a second screen, producing a series of brilliantly colored bands. He reasoned that the light waves from one slit have to travel farther than those from the other slit, so that, at points where the crests of one wave coincide with the troughs of another, bands of darkness are produced. At other points two crests would coincide to produce light bands of double the intensity produced by the light from either hole. When the light source was of a single wave length, the bands were thus alternately dark and bright; but when white light was used, the bands were colored, because white light consists of a mixture of wave lengths. If any one wave length is extracted from white light, the mixture of wave lengths left produces a complementary[1] color.

Young measured the wave lengths of different colored lights in this way; the dimensions of his apparatus and the breadth of the light bands

[1] Complementary colors are those colors which produce white light when mixed with each other in the proper proportions.

produced provided the necessary data for his calculations. These light waves were found to be very short, about 1/50,000 inch.

Recently Newton's corpuscular theory has found favor again, although the modern concept of energy packets, called quanta, differs considerably from Newton's corpuscles. Rapidly moving electrons and protons have been shown to exhibit some of the properties of waves and to produce interference patterns, while photons, or light corpuscles, are accepted as realities today. At present, therefore, light is considered to be both wavelike and corpuscular in nature, but the wave metaphor and the particle metaphor are used in quite different contexts. Roughly speaking, when we want to know or account for where a beam of light goes, we pretend it is a wave motion; whereas when we want to account for what it does when it gets there we pretend it is somehow corpuscular. Of course this dualism is unsatisfactory — it constitutes a problem to be solved.

Radiant-energy units are now generally referred to as *photons*. The amount of energy of photons varies with the frequency of the radiations. Photons of red light contain less energy than those of violet. As the frequencies become greater, the energy of the photons becomes greater. Thus, for X rays the photons are so large that they show atomic characteristics. *A. H. Compton* of Chicago has shown that X rays falling on electrons scattered as if they consisted of material particles.

How Waves Transfer Energy.

Huygens proposed the existence of a hypothetical medium for the waves to travel in, which he called "ether." Ether is a hypothetical medium that is supposed to occupy otherwise unoccupied space.[1] The concept of ether is useful, but it must be kept in mind that there is no experimental evidence for its existence. It is not known how light really travels, but an exact account of its path can be given if it is regarded as a train of waves.

Light waves are supposed to be propagated through the ether in a manner somewhat analogous to the propagation of water waves. If a stone is thrown into a pool of water, the surface will be depressed momentarily, and a series of circular waves will spread from that point. Finally the waves reach the shore and move small objects. The energy used to do work on these objects is transmitted by the waves from the stone. Now, if stones are thrown into a pool at the same rate in rapid succession, the waves formed will move at the same rate, but the distance from crest to crest and from trough to trough will depend upon

[1] Eddington defines ether as follows: "Ether is the subject of the verb, to undulate."

the number of stones thrown per minute. If the wave front moves out twenty feet in one second and ten stones are thrown per second, there will be ten waves produced, each two feet in length. The length of the wave times the frequency (*i.e.*, the number of waves per second) will equal the velocity of the wave, or the distance covered by the wave front in a second.

The Wavelike Nature of Light Is Confirmed by the Nicety with Which It Fits into the Electromagnetic Spectrum.

When it is not in our power to discern what is ultimately true, we should subscribe to what is most probable. — Descartes.

Clerk Maxwell (1831–1879) worked out equations which summarized the knowledge of his time concerning electricity and magnetism, that included the concept of ether and seemed to apply to light. *Michael Faraday* had already suggested that light and electromagnetic forces might be phenomena of ether. On the basis of these equations Maxwell advanced the hypothesis that light is an electromagnetic wave. In 1888 *Heinrich Hertz* showed that electromagnetic waves sent out from an electric spark have all the properties of light rays and thus verified Maxwell's hypothesis.

All radiant waves are now considered to be produced by the motion of electromagnetic lines of force, and hence the radiation spectrum is properly called the "electromagnetic spectrum." Electromagnetic lines of force will be discussed in Unit VII.

Although the nature of light is not well understood, it fits into the electromagnetic spectrum so beautifully that there is little doubt concerning the wavelike nature of light. The wave length of any type of electromagnetic radiation can be measured, and the electromagnetic spectrum was constructed on the basis of such measurements. The accompanying insert shows the electromagnetic spectrum as it is known today.

Our knowledge of radiant energy is still very limited, and many portions of the electromagnetic spectrum remain unexplored.

Ultraviolet Radiations Are of Great Importance.

The biological effects and chemical effects of light become conspicuous in the shorter wave lengths just beyond the limit of visibility to the eye, which fails to respond to any wave lengths shorter than 3800 angstroms. The atmosphere on a clear, dry day transmits light of wave lengths as low as 2900 angstroms. In higher altitudes the ultraviolet light is transmitted more than in lower altitudes, so that a sunburn is rapidly obtained even on cold days at high altitudes. At

lower altitudes, when there are considerable smoke and humidity, the ultraviolet rays below 3200 angstroms may be absorbed. Inasmuch as the radiations between 2900 and 3100 angstroms are most effective biologically, it can readily be understood why ultraviolet lamps are of distinct value to people who live in cities where smoke vies with clouds to screen out most of the biologically useful ultraviolet light during the winter months. There seems to be little doubt that the widespread popularity of out-of-door life and exposure to sunlight has a sound physical and physiological basis.

Ultraviolet lamps have been used as a substitute for sunlight in producing a healthy tan and in producing vitamin D in the human body, as well as in stimulating various body functions.

Ultraviolet radiations are now widely used to irradiate milk, cereal, and other products, for such irradiation produces vitamin D in these foods.

Ordinary window glass does not permit the passage of these health-giving ultraviolet rays, but quartz transmits them freely. Certain types of glass are now manufactured which do permit the passage of ultraviolet light.

Ultraviolet radiations are of special interest to the chemist because they affect the outer electrons in atoms.

Recent studies show that plants thrive best under red light and that ultraviolet light has a definite retarding effect upon plant growth.

The Shorter Wave-length Radiations Likewise Activate Chemical Changes.

X rays, whose production will be discussed in the next Unit, are more penetrating than ultraviolet rays and involve the displacement of inner electrons within atoms.

Short-wave radiations, especially X rays, modify the chromosomes in living cells. Thus even the sex of flies has been changed by X rays. A lintless cotton has been grown from X-rayed seed.

Gamma rays, produced by radioactive disintegration, are still more penetrating and displace electrons in the central parts of atoms. The applications of X rays and gamma rays will be studied in the next Unit.

Cosmic rays, studied by Millikan and many others, are the shortest of all waves and are exceedingly penetrating. A high percentage of cosmic rays consists of high-speed particles, electrons or protons rather than photons, which possess enormous energies. While it is true that a high proportion of cosmic rays are particles rather than waves, the term "cosmic ray" is still used, just as cathode rays, beta rays, and alpha

In these cases the term "ray" refers to straight-line propulsion rather than to wavelike radiations.

Infrared Rays Are Heat Rays.

Infrared rays, or heat rays, are invisible radiations contained in sunlight which are longer in wave length than the visible light rays. Everyone is familiar with the fact that heat can be radiated. The use of reflectors in electric and gas heating devices shows that heat rays can be reflected just as visible rays are reflected.

Smokestacks or airplane exhausts may be detected by the effect of their infrared radiations on sensitive thermocouples six miles away, and icebergs may be located in the fog by their coldness.

A "fog-eye" recently developed consists of a reflector which gathers in infrared rays and focuses them on a thermocouple. The electricity generated by the thermocouple is amplified millions of times by amplifiers and may be used to ring warning gongs when a ship is approaching an iceberg. The "fog-eye" can detect a difference of temperature of one fifty-thousandth of a degree, which means that it should respond to the heat of a candle eight miles away. This instrument is mounted on a tripod, which is kept swinging back and forth through a semicircle, scanning the horizon through fog, smoke, or the blackness of night. Had the *Titanic* been equipped with a "fog-eye," one of the greatest marine disasters of history would have been averted.

Thermocouples thus do for infrared radiations what the photoelectric cell does for visible and ultraviolet radiations. A thermoelectric sextant has been devised to measure the position of the sun through obscuring clouds by means of infrared radiations.

Inasmuch as infrared rays penetrate the atmosphere better than the radiations of shorter wave length and inasmuch as they affect certain photographic emulsions, infrared rays may be used in photography in cases where the shorter waves are scattered by the atmosphere. Excellent photographs are often made of distant objects on hazy days by use of films especially sensitive to infrared rays and employing an infrared filter that screens out all but the infrared rays.

Figure 169 shows what can be done with infrared photography. Pictures have been taken in a dark room with the heat rays from a hot iron, as shown in Figs. 170 and 171.

In infrared photographs, the leaves of trees and grass appear white. Because no known green paints have the same appearance in infrared photographs, it is possible to distinguish between natural foliage and camouflage.

Moonlight effects are simulated in the movie industry by taking infrared pictures in the daytime.

Many stars which are so cool that they do not emit visible light have been discovered by infrared photography.

Infrared photography is very useful in examining paintings and in the study of documents and textiles.

FIG. 169. The Sierra Nevada range in the vicinity of Yosemite, photographed from Mount Hamilton by infra-red light; distance to Half Dome, 120 miles. (Courtesy of the Lick Observatory.)

Infrared lamps are now widely applied in speeding up the baking of enamels and lacquers on automobiles, refrigerators, washing machines, and furniture. By the use of infrared lamps, sheet rubber may be cured in two minutes instead of the two hours formerly required. These lamps may even be used to bake cookies. Soon infrared lamps may be used to dry the family washing or to keep one warm in cold weather.

An infrared telescope was patented in 1940. It is based on the fact that fluorescence is speeded up by heat. The telescope focuses infrared rays on a fluorescent screen which is continually flooded with ultraviolet rays. Where the infrared rays fall upon the screen, the fluorescence [1] increases, and the picture appears.

A closed automobile warms up when placed in sunlight because of

[1] Fluorescence is the emission of visible light by an object which is irradiated with electromagnetic radiations of shorter wave length.

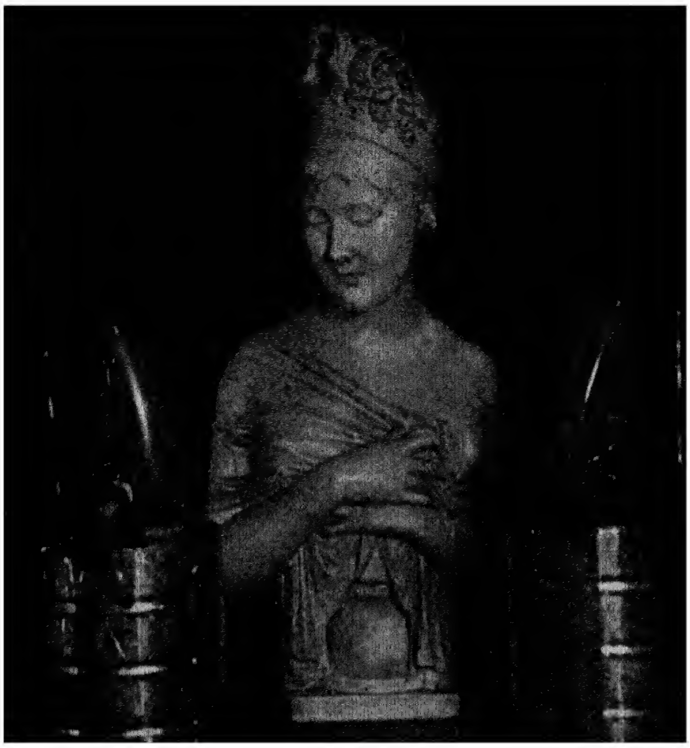


FIG. 170. The irons shown in this figure were heated to produce the infra-red radiations which were used in taking the photograph shown in Figure 171. (Courtesy of the Eastman Kodak Company.)

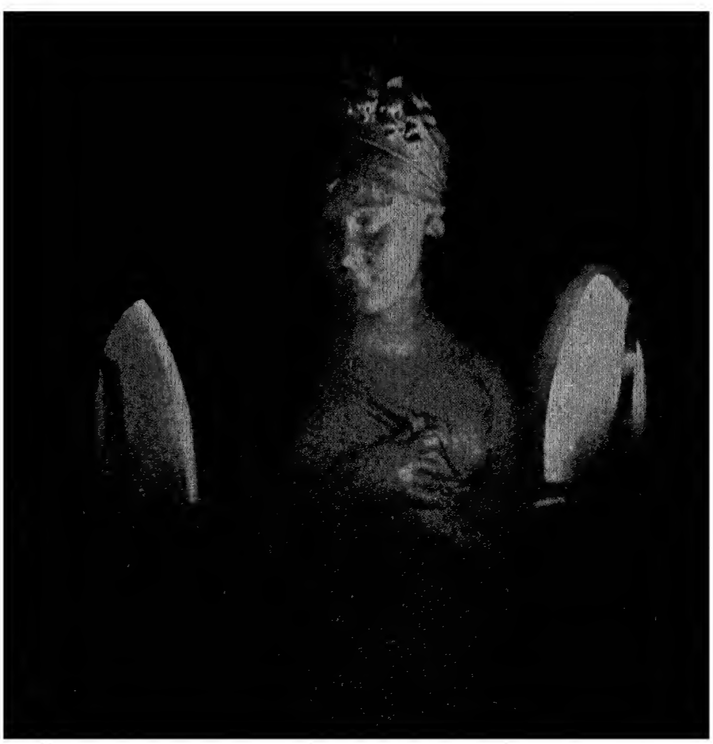


FIG. 171. The photograph obtained using an emulsion sensitized to infra-red radiations. The irons were not hot enough to produce any visible light in the perfectly dark room. (Courtesy of the Eastman Kodak Company.)

two properties of glass. In the first place, glass transmits short infrared waves such as come from the sun, but it does not transmit the longer infrared rays such as come from warm objects in the car. In the second place, glass is a poor conductor of (sensible) heat. The transmission of short infrared rays by glass is a very important factor to be considered in air conditioning. The behavior of glass toward infrared rays is applied in greenhouses and hotbeds.

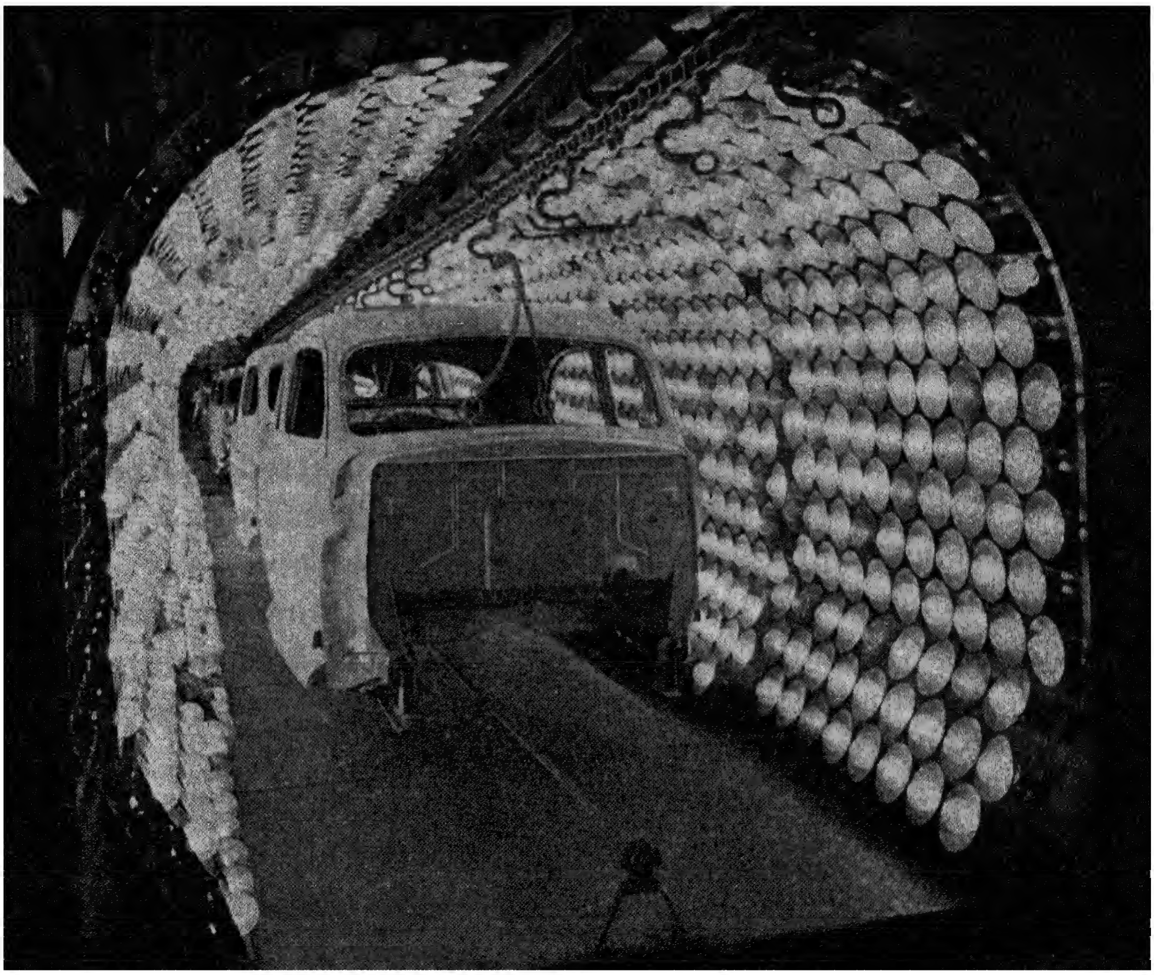


FIG. 172. One of the tunnels through which automobiles are drawn at the Ford River Rouge plant, to dry the enamel by the infra-red rays from a battery of lamps. (Courtesy of the Ford Motor Company.)

The heating of objects by sunlight represents a special type of fluorescence because infrared rays of long wave length are emitted when the objects are irradiated with infrared rays of shorter wave lengths.

The infrared spectrometer enables the chemist to detect the presence of molecules of organic compounds just as the visible spectrometer is used to detect the presence of atoms. Infrared rays are passed through a solution of a substance and are then separated into an absorption spectrum by a rock-salt prism. Inasmuch as the bands of the absorption spectrum are not visible to the eye, their presence and intensity are measured by a thermopile. Each organic compound has a charac-

teristic absorption pattern, which is identified by matching it with patterns of known substances previously determined.

Ultrashort Radio Waves Have Many Applications.

Radio waves of less than ten meters in wave length are called ultrashort radio waves. Previous to World War II they were used for a two-way wireless telephone between France and England which employed radio waves 18 cm. in length.

The shortest of these waves have been investigated only since 1928. They were first produced by oscillating electric sparks, but later vacuum tubes were used, because the waves produced by sparks are a mixture of wave lengths. The smallest waves originally produced with vacuum tubes were 30 cm. in length. When oscillations of sufficiently high frequencies to produce shorter waves were generated, the materials of the tube broke down because of the intensity of the resulting electric fields. Later it was found that these frequencies could be reinforced by proper tuning to produce much shorter waves.

Ultrashort waves can be focused and transmitted in the form of narrow beams less than a square centimeter in cross section. This concentration of energy presents the advantage that no energy is wasted. An overwhelming proportion of the energy of longer radio waves is wasted in space without being received. The ultrashort radio telephone between France and England, mentioned above, requires an energy output of only a fraction of a watt.

Short radio waves, about seven meters in length, with a frequency of 42,000,000 cycles per second, are now used to kill eggs, larvae, and pupae of insects concealed in grain. Weevils, worms, mites, and other infestations of cereals, cocoa beans, spices, tobacco, nuts, and similar products are thus killed without injury to the products themselves.

It has been found that paresis, a disease due to syphilis, can be cured by inducing malaria fever. In 1930 *Whitney* (1868–   ) found that a fever could be induced and controlled by short radio-wave transmitters. Since that time many cases of paresis have been cured by this method, although the old malaria method is still preferred by some physicians. Many remarkable experiments can be carried out with powerful short-wave transmitters. For example, electric-light globes can be made to glow several feet from the transmitter without the use of any conductor. Popcorn can be popped in a cake of ice; meat can be cooked in mid-air. So far the results obtained with such transmitting devices have been more novel than valuable, but many possibilities of practical applications are open.

Radiations of various kinds bring about profound changes in the

growth of living things, particularly seeds or primary cells; for example, onions treated with two-meter waves bloom ten days before non-exposed plants.

Ultrashort radio waves transmit energy more efficiently than do longer radio waves.

STUDY QUESTIONS

1. Upon what evidence did Young base his conclusions concerning the nature of light?
2. How do light quanta differ from one another?
3. List the most important types of electromagnetic waves.
4. State two fundamental properties of wave motion.
5. Outline briefly the two light theories. What is their status today?
6. How should the speculations and theories of scientists be treated by the average individual?
7. Discuss the value of infrared photography.
8. Discuss the physiological effects of ultraviolet rays.
9. Compare the different electromagnetic rays as to their ability to penetrate matter and their physiological effect.

UNIT VI

SECTION 2

LIGHT MAY BE PRODUCED BY LUMINESCENCE

Many substances radiate light when heated to a high temperature; this process is called *incandescence*. It is not necessary, however, to heat objects in order to cause them to emit light. Various types of energy are used to produce cold light, the process being called *luminescence*. Several forms of luminescence are still laboratory curiosities; but other forms, such as electroluminescence, fluorescence, and phosphorescence, discussed in this Section, have graduated from the laboratory during the past twenty years and are being employed in many useful applications, even to the extent of revolutionizing such industries as electrical advertising and Mazda-lamp manufacture.

Luminescence or Cold Light May Be Produced by Various Forms of Energy.

Bioluminescence is well illustrated by the firefly. Fireflies have long excited the curiosity of man. The firefly's light is produced by the oxidation of a protein-like substance, luciferin, in the presence of moisture and the catalyst, luciferase, an enzyme. Some people have thought that the mastery of the secret of the firefly would yield the most efficient light because the light of the firefly is cold, but actually the firefly is less efficient than any common type of lighting equipment, considering the amount of oxygen required to produce a given amount of light. The flashes of light by the firefly are produced by forcing air to the luminous cells. Glowworms are the larvae of fireflies.

Besides fireflies, bioluminescence is produced by certain kinds of beetles, by bacteria that cause meat or dead fish to glow, by noctiluca, the one-celled animals in ocean water that glow when disturbed, by deep-sea fish, and by thousands of species of mollusks, shellfish, centipedes, jellyfish, marine worms, and earthworms.

Chemiluminescence may be produced by various chemical reactions not associated with life. For example, photographic pyrogallol will give an orange-red luminescence when treated with formaldehyde and hydrogen peroxide in a strongly alkaline solution. Luminol, 3-aminophthalhydrazide, gives a brilliant blue light when oxidized. Citric acid,

cane sugar, starch, and many other similar materials show chemiluminescence when fused and then oxidized.

An interesting application of chemiluminescence is a powder, "Bloodglo," developed by *Evans W. Cottman* for use in criminology and medicine. The powder is dissolved in water. When the solution comes into contact with the merest trace of blood, it glows in the dark, the haemoglobin acting as the oxidizing agent.

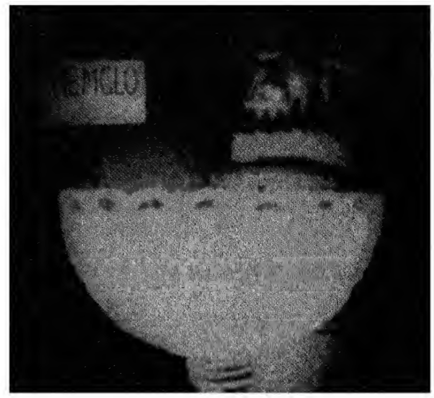


FIG. 173. A glass bowl is caused to glow by chemiluminescence. (Courtesy of Evans W. Cottman.)

Electroluminescence is produced when electricity is passed through vacuum tubes containing traces of gas. Neon tubes produce light by electroluminescence. Brush discharges such as St. Elmo's fire, which appears as a tip of light on ship masts or church spires, are electroluminescence.

Radioluminescence is produced by radioactive substances.

Crystalloluminescence is the emission of light when certain substances crystallize from solution.

Triboluminescence is the production of light by crushing certain crystals.

Acousticoluminescence is the production of light by vibrating viscous liquids such as glycerol at a high frequency.

Still another type of luminescence is produced by friction such as appears when tire tape or adhesive tape is stripped from a roll or when mercury is distilled under reduced pressure.

It is apparent that nearly every form of energy may be changed directly into light energy. Most of the forms of luminescence are still laboratory curiosities, although electroluminescence is widely used in neon-type lights and in mercury- and sodium-vapor lamps. Still another type of luminescence, phosphorescence and fluorescence, described in this Section, is applied in modern fluorescent lighting. No one can tell just what great possibilities the remaining laboratory curiosities may have in the service of mankind. Falling snowflakes, waterspouts, and dust from volcanic eruptions sometimes luminesce. The Aurora Borealis is another luminescent phenomenon. Very little is known about the causes of these examples of natural luminescence.

Mercury-vapor Lamps Produce Light by Luminescence.

About 1900 *Peter Cooper Hewitt* developed the mercury-vapor lamp, which is used in photographic studios because of its highly actinic

yellow-green light. The great disadvantage of these lamps is that the faces of people take on a deathlike appearance in their yellow-green light, and colors cannot be matched. This difficulty is partly overcome by the use of reflectors, on which red fluorescent materials have been placed so as to add the red rays that are missing, and by locating incandescent lamps in the same fixture.

A new type of mercury-vapor lamp used in television studios because it gives such an intense, yet cool, light is the water-cooled mercury-vapor quartz-tube light. The lamp itself is a quartz tube of very fine bore about 1½ inches long, about the size of a cigarette. Tungsten wires are sealed into each end; and a small amount of mercury, together with argon at a pressure of about one pound per square inch, is contained in the tube. When the electricity is turned on, the mercury vaporizes and produces a pressure of about 1200 pounds per square inch. The tube produces a great deal of heat and must be cooled by water. Its light output is 65,000 lumens, and it is ⅕ as bright as the sun. Mercury-vapor lamps are of special interest because they are excellent sources of ultraviolet radiations, which cause fluorescence.

Sodium-vapor Lamps Produce a Yellow Light That Is Excellent for Certain Types of Illumination.

The sodium-vapor lamp is another type of lamp which employs electroluminescence. The sodium-vapor lamp employs the principle of the mercury-vapor lamps, except that sodium replaces the mercury. The sodium-vapor lamp contains neon gas for starting and thus has the characteristic red color of neon luminescence until the lamp gets warm enough to vaporize the sodium.

Sodium-vapor lights are especially adapted for safety lighting for highways, bridges, and underpasses, their chief advantage being their relatively high efficiency as compared with tungsten-filament lamps.

Electromagnetic Waves Shorter than Those of Visible Light Produce Fluorescence and Phosphorescence.

Some materials, when irradiated by light of one wave length (color), will emit light of a different, but always longer, wave length. Such radiations are called "luminescence," or "cold light." The explanation is based on the electronic theory of the atomic structure, to be discussed in the next Unit. It is sufficient to state here that according to the electron theory this light is emitted when electrons which have been displaced from their normal or stable position in the atoms by bombardment with some form of energy particles return to their original condition.

Cathode rays, X rays, gamma rays, and, in general, any type of electromagnetic radiation having wave lengths shorter than those of visible light can produce luminescence. Ultraviolet rays are widely applied to produce luminescence.

If the luminescence lasts during the period of excitation only, it is called "fluorescence." If the luminosity persists after removal of the exciting radiation, it is called "phosphorescence."

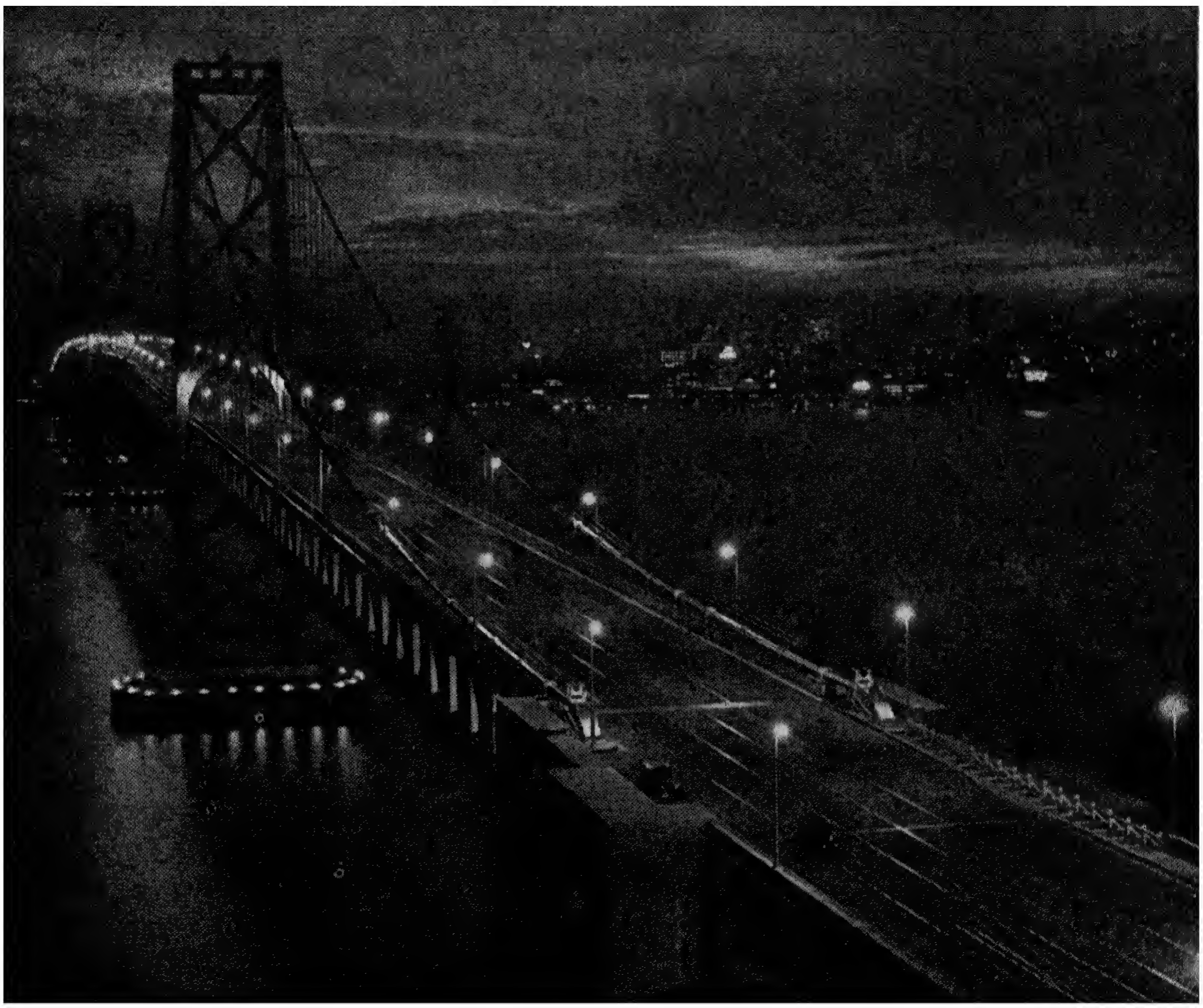


FIG. 174. Sodium vapor lamps illuminate the San Francisco-Oakland Bay Bridge. (Courtesy of the Pacific Gas and Electric Company.)

Zinc sulfide may be obtained in different forms, which show a red, yellow, blue, or green phosphorescence. Phosphorescent paints are used for theatrical displays, exits, danger signals, signs, and advertising purposes.

Sources of Ultraviolet Light.

Small argon lamps, which can be operated in ordinary light sockets and by ordinary lighting current, give off a light containing ultraviolet rays. When ultraviolet light alone is desired, filters of special glass which absorb the visible light rays are employed.

Special incandescent lamps, made of glass that permits the passage of ultraviolet rays but absorbs the visible light, are also available. The life of these lamps is short because of the high temperatures required for ultraviolet production with filament sources.

More intense sources of ultraviolet rays use either an electric arc or a mercury-vapor lamp with a suitable filter.

Modern photoflood lights produce radiations so rich in ultraviolet rays that several of these lights, placed in a box with a window made of a kind of glass that filters out all but the ultraviolet radiations, provide an inexpensive source of ultraviolet rays.

The Wave Lengths of Ultraviolet Light Sources Vary.

The wave lengths of ultraviolet radiations may range from 136 angstroms to 4000 angstroms.

The wave lengths of ultraviolet rays may be determined by chemical reactions which are influenced by a certain range of wave lengths only.

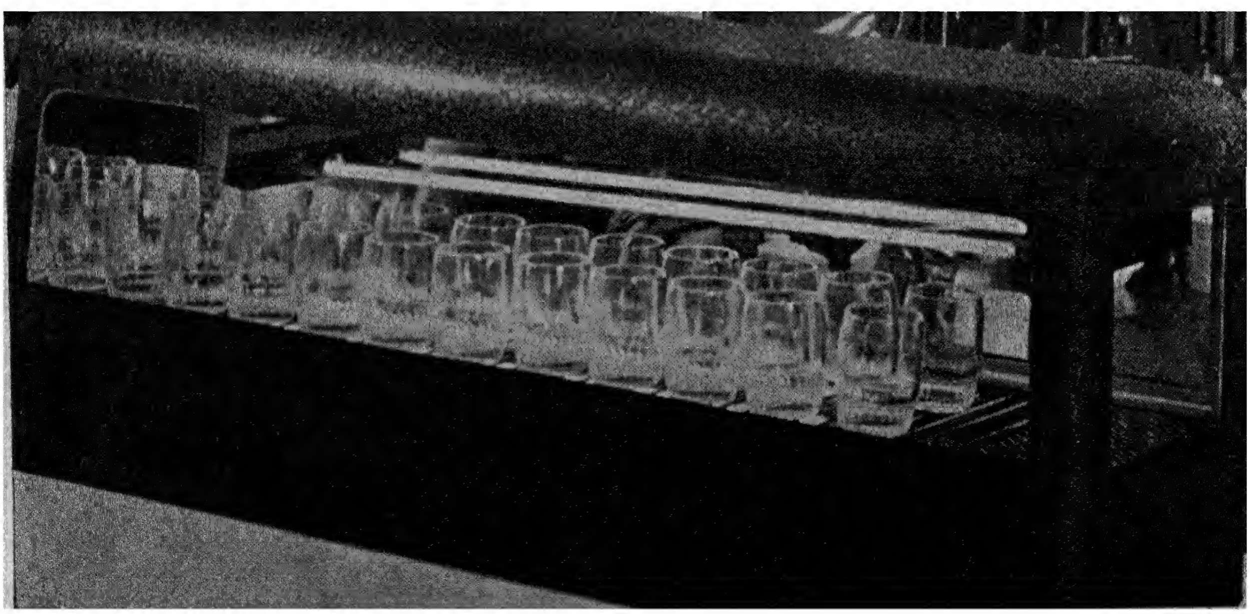


FIG. 175. Germicidal lamps used to sterilize glasses in a cafeteria. (Courtesy of the Westinghouse Electric and Manufacturing Company.)

Thus the range 2200–3200 A. liberates iodine from potassium iodide, potassium nitrate is reduced to potassium nitrite by a range of 2200–4000 A., and methylene blue is decolorized by light of 2500–4000 A.

The wave length most effective against bacteria is about 2600 A. Radiations between 3300 and 4000 A. do not affect the body and do not have germicidal action, while the shorter wave lengths produce "sunburns" and conjunctivitis of the eyeball. The wave lengths emitted by different ultraviolet-ray sources depend upon the temperature of the radiating sources, the nature of the glass in the lamp, the nature of the filter, and other factors.

Germ-killing Lamps Are Ultraviolet Sources.

Germ-killing lamps, such as the "Sterilamp," "Sterilaire," and General Electric "Germicidal" lamps, use a very thin layer of glass of a type that transmits a high percentage of ultraviolet light. Most lamps of this type operate on low current, about as much as a Christmas-tree light, and develop very little heat. The wave lengths of the ultraviolet radiations produced by such lamps are deadly to bacteria; such radiations cause temporary, but very painful conjunctivitis of the eyeball. Goggles may be worn to protect the eyes against these radiations. Germ-killing sources have been used in refrigerators and display cases to keep foods such as meat fresh much longer, and they have improved the health of cows in dairies and lowered the death rate of chicks in brooders by reducing air-borne contamination. They sterilize the air in operating rooms, thus decreasing the possibilities of infections. Wounds may be kept sterile until they heal, and skin infections may be killed. Such sources may be used in restaurants to sanitize drinking glasses and other utensils. In general, this source of mold-, fungi-, and bacteria-killing ultraviolet light is in many fields the most important prophylactic germicidal agent now available.

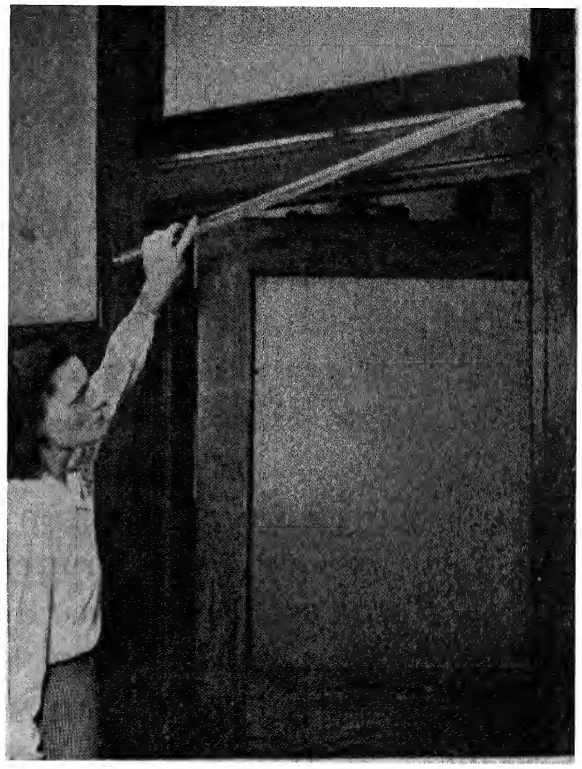


FIG. 176. This yard-long germicidal lamp promptly destroys a high percentage of the bacteria borne by air currents through this doorway. (Courtesy of the General Electric Company.)

Neon-type Lights Revolutionized Electrical Advertising.

Neon lights were invented by a Frenchman, *Georges Claude*, who also invented a process for liquefying air that made it possible to obtain neon and the other rare gases from the air. The first neon lights used in the United States were set up in Los Angeles and San Francisco in 1924.

Claude found that the rare gases would glow when placed in tubes under low pressures, at relatively low temperatures, when a high-voltage current was passed through them. Neon vapor gives a red light; mercury vapor, a blue light; and helium, a white light. Other colors are produced by the use of tinted glass.

High-voltage fluorescent tubing known commercially as "zeon" (the N of Neon becomes the Z of Zeon when tipped on its side) lights are similar to neon lights in that they use long tubes and high-voltage circuits, but they differ from neon lights in that the tubes are coated inside with fluorescent materials. Both neon and zeon lights generate ultraviolet radiations, but these radiations are absorbed by the glass in neon lights without producing useful illumination, while the fluorescent powders in zeon lights convert the ultraviolet radiations into visible light. Any desired hue can be obtained with zeon lights, while the choice is scant with neon lights.

Fluorescent Lamps Are Low-voltage Lamps Which Are Finding Widespread Adoption.

The fluorescent lamp is a long tube coated inside with a fluorescent material. The tube contains a small amount of mercury, which sets up a mercury arc when electricity is passed through the tube. This mercury arc produces ultraviolet radiations, which energize the fluorescent materials, causing them to give off visible light.

In addition to the trace of mercury, there is a small amount of argon gas at low pressure. The argon serves as a starter to conduct the current until the tube gets warm enough for the mercury vapor to do so.

Fluorescent lamps produce a stroboscopic effect when an object is moved rapidly in their light because these lamps are operated by alternating currents which cause the light to go on and off 120 times a second. It is true that incandescent lamps are likewise usually operated by alternating current, but in this case the light is produced by a hot filament which remains incandescent between the electrical impulses and thus gives an almost continuous light. Two fluorescent lamps may be operated with certain auxiliary equipment in such a way that one glows while the other one does not, thus yielding a nearly continuous light.

The flicker in fluorescent lamps is not noticed except when their light falls upon moving objects because the phosphorescence tends to keep the light fairly continuous. The discovery of a really good phosphorescent material would greatly reduce the stroboscopic effect of fluorescent lamps.

Fluorescent lamps are more expensive to install than ordinary incandescent lamps because auxiliary control apparatus is required. Inasmuch as the fluorescent lamp operates on a relatively low-voltage (110 volts) circuit, it must have its electrodes heated for starting. An automatic switch closes the electric heating circuit when the electricity is first turned on and opens the circuit as soon as the lamp begins to

glow. A capacitor is often added to bring up the power factor, and a choke coil called the ballast must always be present to keep the current from increasing to a point where the lamp would melt. A complete line of high-power-factor ballasts is available, and, when such ballasts are used, no additional capacitor is required.

Common fluorescent lamps have an average life of 2500 hours; most filament lamps are rated at 750 to 1000 hours.

The 30-watt fluorescent lamp produces from 30 to 75 lumens of light per watt, depending upon the color, while a standard 100-watt incandescent lamp produces only 16 lumens per watt. In general, fluorescent lamps are from 200 to 300 per cent more efficient in light output,

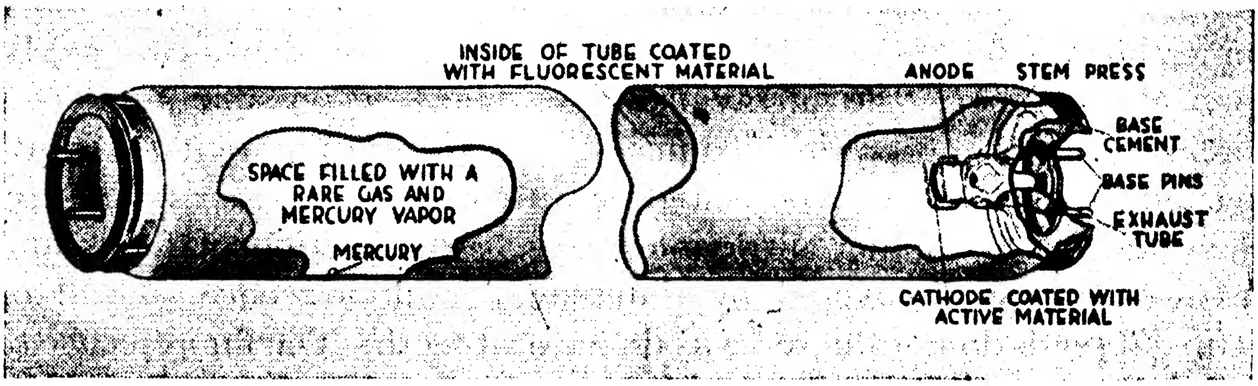


FIG. 177. The construction of the fluorescent lamp. (Courtesy of the General Electric Company.)

color for color, than comparable incandescent sources. Incandescent lights waste in the form of heat most of the energy furnished. Neon lights are more efficient than incandescent lights because very little energy is lost in the form of heat, but they are still much less efficient than zeon or fluorescent lamps because they do not utilize the ultraviolet light that is produced.

A great deal of research has been carried out on materials suitable for producing fluorescence in fluorescent tubes. Calcium tungstate has been selected to produce a blue color; magnesium tungstate, a blue-white; zinc silicate, green; zinc beryllium silicate, yellow-white; cadmium silicate, yellow-pink; and cadmium borate, pink. These materials are carefully purified and treated by heating them in electric furnaces.

Pure zinc sulfide is not fluorescent; but a trace of radium, copper, lead, or silver will make it fluorescent. The mechanism of the action of these impurities is not understood.

The addition of a small amount of manganese is generally employed to activate fluorescent powders.

Mixtures of fluoescent pigments are used in the daylight fluorescent lamps that come closer to the color of natural daylight than any other

practical high-efficiency source thus far produced. The use of pink "Louverglas" slightly reddens the daylight fluorescent lamp radiations, thus permitting a still closer approach to natural daylight.

The large light-producing area of fluorescent lamps, the high diffusion of the light from these lamps, their high efficiency, and low radiant heat make them very desirable for general illumination; and they have many excellent supplementary lighting applications.

Ultraviolet Fluorescence Has Many Practical Applications.

The modern "black light" analysis depends upon the fluorescence or phosphorescence produced in many substances by filtered ultraviolet radiations. Certain minerals possess a characteristic fluorescence under ultraviolet rays, which is useful for means of identification. In forensic chemistry the ultraviolet rays make it possible to detect forgeries and alterations in documents. In art the authenticity of paintings and sculptures may be tested because overpainting, patches, etc. show up at once under ultraviolet rays. Adulteration of foods and textiles can be discovered by differences in fluorescence. Dead or artificial teeth do not fluoresce as do natural teeth. The fluorescence of eggs increases with age. Hair dyes and oils show up under the fluorescent light. In a Chicago hospital, babies are "sunburnt" with an identification mark visible only under ultraviolet rays.

Cigarette stamps made from materials containing quinine will glow with a blue color in ultraviolet rays, thus differentiating them from counterfeit stamps which are not fluorescent.

Safety paper containing quinine or uranium salts makes it possible to detect forgeries readily. Secret messages written with saliva, milk, soapsuds, and other materials available to prisoners show up under ultraviolet rays.

Phosphorescent wall papers which will glow for a sufficient time to enable one to avoid hitting his shins against the furniture after turning out a light are now available.

It was possible to find one's way about in city streets during "blackouts" in World War II because street signs and direction-markers were made from fluorescent pigments that glowed in the "black light" from ultraviolet lights.

Golf tees are now made from a cellulose acetate plastic that contains a yellow fluorescent pigment, which causes the tees to glow brilliantly in the sunlight, thus making them easy to find after use.

Ring rot of potatoes, which has invaded 37 states and destroyed up to 50 per cent of the crop in some localities, is produced by a germ in the seed potatoes. The infected seed potatoes glow with a

greenish light in ultraviolet rays and may thus be easily detected and culled out.

Many minerals fluoresce with characteristic colors that aid in their location and identification. One prospector using a portable ultraviolet lamp spent many nights in the California desert looking for the

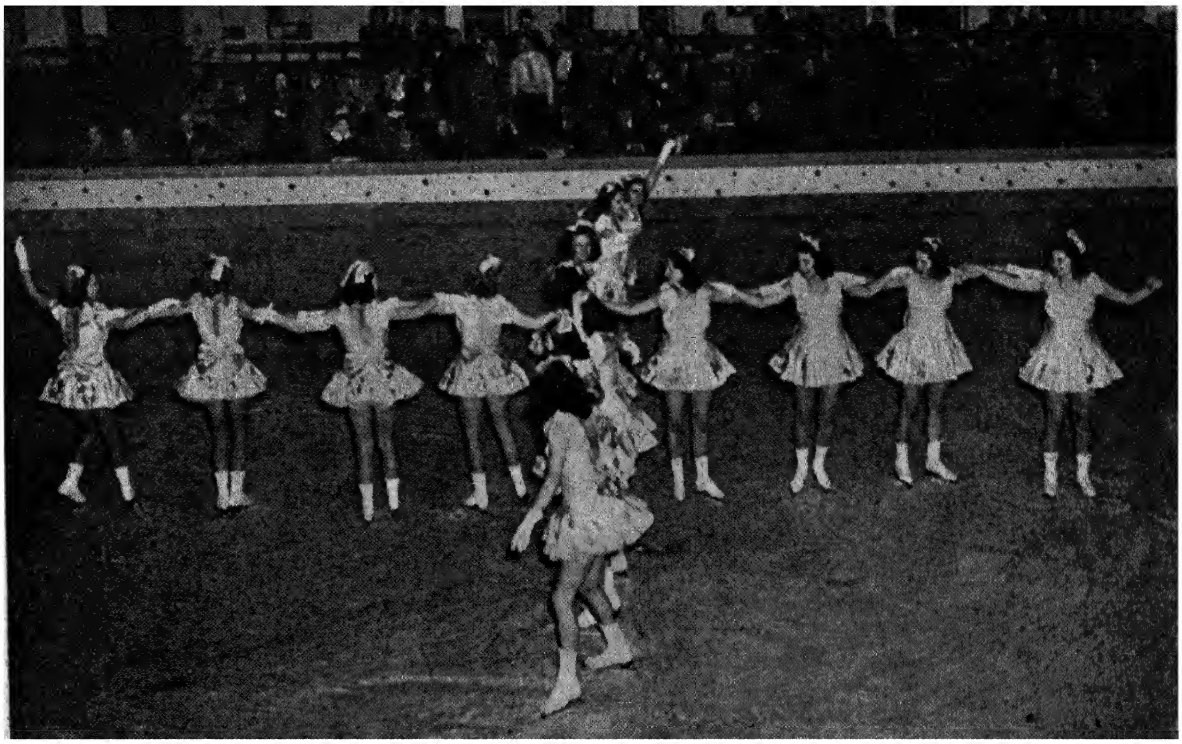


FIG. 178. Ice-skaters in ordinary light. (Courtesy of the Continental Lithograph Corporation.)

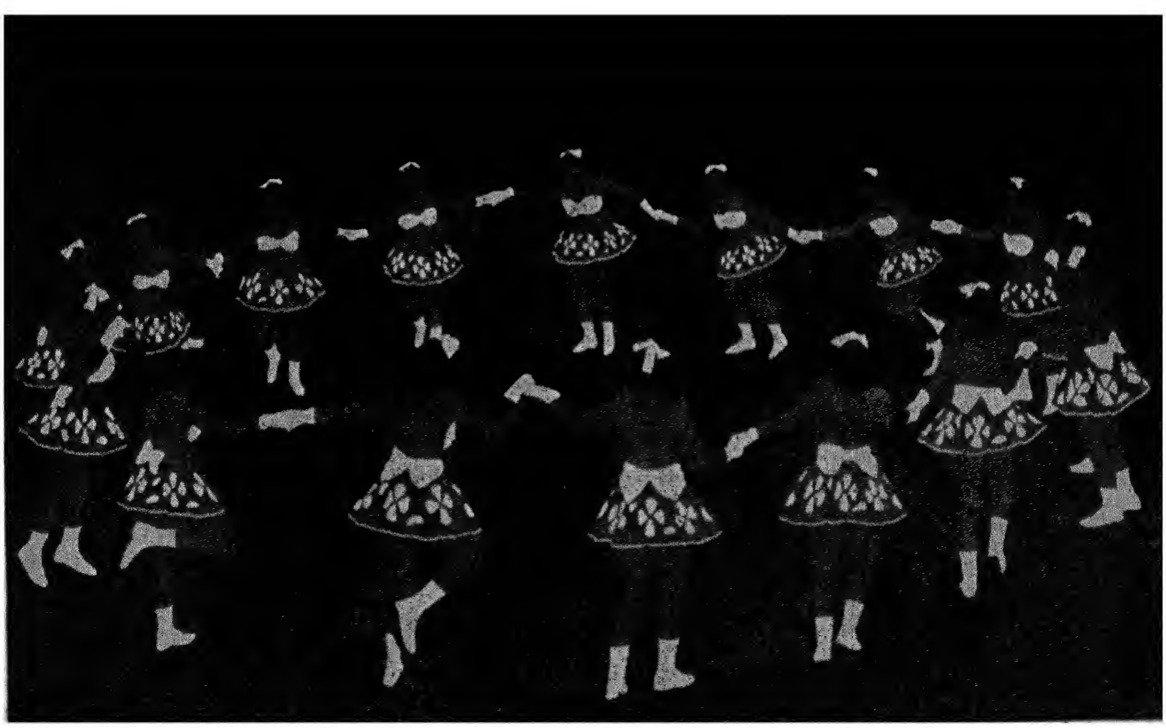


FIG. 179. Ice-skaters' fluorescent costumes glow in ultraviolet light. (Courtesy of the Continental Lithograph Corporation.)

telltale glow that will reveal the outcroppings of scheelite, a tungsten ore. Traces of oil in the mud obtained in oil wells may be detected by the typical fluorescence in ultraviolet rays.

Ultraviolet rays are used in making a rapid microscopic test of sputum for the presence of tuberculosis bacteria. The sputum is treated with carbol-auramin, which dyes the bacteria and causes them to glow as bright yellow rods in ultraviolet rays. The use of this technique has greatly decreased the time required for a sputum test.

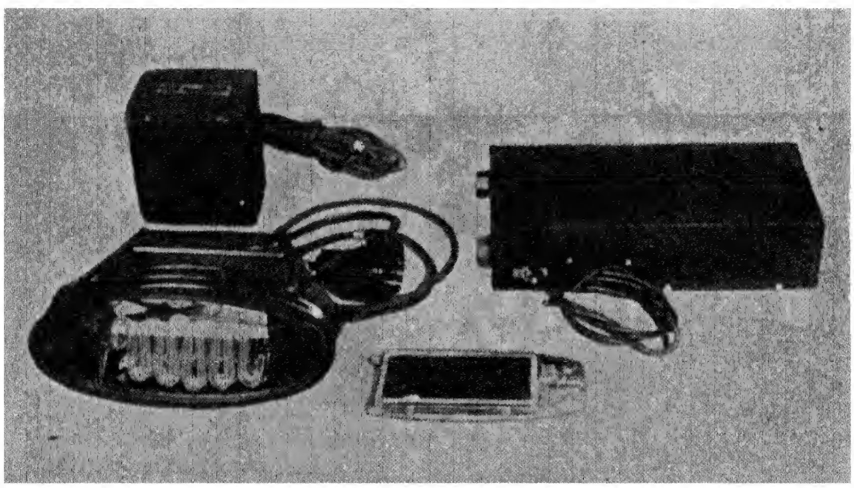


FIG. 180. A portable ultraviolet kit for prospectors. (Courtesy of Ultraviolet Products, Inc.)

The lens of the eye is markedly fluorescent, and a light haze in the lens is observed in ultraviolet rays. A special ultraviolet lamp is used to cause the eye to fluoresce and thus helps in cataract surgery.

Novel outdoor advertising signs have been made possible by the use of fluorescent paints and lacquers and ultraviolet lamps. The whole sign will appear the same at night as in the daytime when in the light from ordinary incandescent light bulbs; but when these lights are turned off, only those portions of the sign painted with fluorescent paints will glow in the radiations from ultraviolet lamps. During the day the fluórescent materials are invisible.

Designers of zeon advertising signs paint miniatures of these signs with fluorescent paints that will glow in ultraviolet rays in such a way as to show exactly how the zeon signs will look at night as well as in the daytime.

The availability of powerful and economical sources of ultraviolet radiations would make possible many other interesting light effects; for example, whole ceilings could be constructed of glass panels coated with fluorescent pigments and be caused to glow by ultraviolet sources placed behind them, thus providing a source of diffuse light closely

resembling that of the sky. Panels of translucent plastics containing fluorescent substances could be used in floors, walls, or ceilings and be made luminous by concealed ultraviolet lamps. Houses could be painted with fluorescent paints that would cause them to glow in the radiations from concealed ultraviolet lamps. Fluorescent materials could be dissolved in the water in fountains, exposed to ultraviolet rays.

Many inexpensive dyes are fluorescent and thus make possible the manufacture of dyed carpets and dresses, etc. which will fluoresce brilliantly in ultraviolet rays. A number of theatres have their aisles covered with rugs dyed with fluorescent dyes. Special fluorescent lipstick, fingernail polish, face powder, hair preparations, and other cosmetics may be worn for visits to restaurants, theatres, and other places where ultraviolet lamps are used to achieve unusual lighting effects.

FIG. 181. "Glowing Carpets" might be the appropriate name to apply to the fluorescent carpet which shines in brilliant colors when irradiated with ultraviolet light. The carpet is used for theater aisles. The ultraviolet lamps used to cause the dyes in the carpet to fluoresce are concealed in the ceilings or elsewhere. (Courtesy of the Calco Chemical Division, American Cyanamid Company.)

STUDY QUESTIONS

1. What is the source of the light in nonfilament lamps?
2. What is luminescence?
3. List the different types of luminescence and give an example of each type
4. Differentiate between phosphorescence and fluorescence.
5. What type of luminescence is illustrated by the firefly?
6. What is the principle of a mercury-vapor lamp?
7. What are the advantages and disadvantages of mercury-vapor lamps?
8. What are the advantages and disadvantages of sodium-vapor lamps?
9. Why are sodium-vapor lamps especially adapted for use on highways?
10. Why do sodium-vapor lamps have a red glow for about a half-hour after they are first turned on?
11. Give a possible explanation of luminescence.
12. Discuss the sources of ultraviolet radiations.
13. Why is it that some ultraviolet lamps are dangerous to use while others are not?
14. Why did the introduction of neon lights revolutionize electrical advertising?

15. In what respects are "zeon" lights an improvement over neon lights?
16. Why are "zeon" and neon lights not used for lighting private residences?
17. Explain the high efficiency of fluorescent lamps.
18. What types of materials are used to produce fluorescence in fluorescent lamps?
19. Explain the stroboscopic effect obtained with fluorescent lamps and suggest two methods of overcoming this effect.
20. Why are fluorescent lamps relatively expensive to install?
21. Can you suggest any reason why high-frequency circuits are not used with fluorescent lamps?
22. What are the advantages and disadvantages of fluorescent lamps as compared with incandescent-filament lamps?
23. Discuss the practical applications of ultraviolet fluorescence.
24. Why are ultraviolet radiations sometimes called "black light"?
25. In what respect are ultraviolet rays similar to light rays?
26. Discuss the applications of fluorescence in war.
27. Discuss the applications of fluorescence in the theatre.
28. Discuss the applications of fluorescence in analytical work.
29. Discuss the application of fluorescence in mineralogy.
30. Discuss the possibilities of the application of fluorescent paints and ultraviolet lamps in outdoor advertising and in home architecture.

*

UNIT VI

SECTION 3

COLORS ARE PORTIONS OF THE VISIBLE SPECTRUM

Introduction.

In the preceding two Sections the characteristics and nature of light were discussed. In this Section we shall learn that the sensation of white light is produced by a mixture of wave lengths, which comprise the visible spectrum, and that each portion of the visible spectrum viewed alone produces the sensation of color.

White Light Is Composed of Light of Various Colors.

When daylight or a bright light is passed through a prism or a diffraction grating,[1] a spectrum or band of colors corresponding to those in the rainbow is obtained. *Newton* studied the spectrum produced by passing light through a prism and also observed that white light was again obtained by passing the light from the first prism through a second prism.

The same effect can be produced by causing the light to be reflected by small mirrors back to one point. Newton explained the formation of the spectrum by saying that white light is composed of light of various colors, which the prism can sort out and disperse or recombine to form white light. The application of a prism to refract light in the spectroscope was discussed in Unit II, Section 3.

It will be recalled that Young measured the wave lengths of different colors. It is now accepted that white light is a mixture of light waves of different wave lengths and hence of different frequencies. The frequency of the light waves increases from the red toward the violet end of the spectrum. The reason that a prism disperses (*i.e.*, separates) the white light is that waves of different frequencies are refracted differently, the waves of higher frequency being refracted the most.

The rainbow is produced by the refraction of the light rays internally

[1] *Diffraction gratings.* Machines have been devised which can rule as many as 30,000 lines to an inch on metal or glass surfaces. When light falls on such a grating, it is reflected by the smooth surface between the lines. The mechanism of this scattering of light by a grating is based on interference.

reflected within raindrops, each ray of light being bent in proportion to its frequency as in the case of prisms. Secondary rainbows are produced when light is twice reflected within the drops. In the secondary rainbow it will be noticed that the colors are reversed. No two observers see the same rainbow, because the rainbow seen by any individual is produced by only those drops which are in the proper position relative to the eyes of the individual.

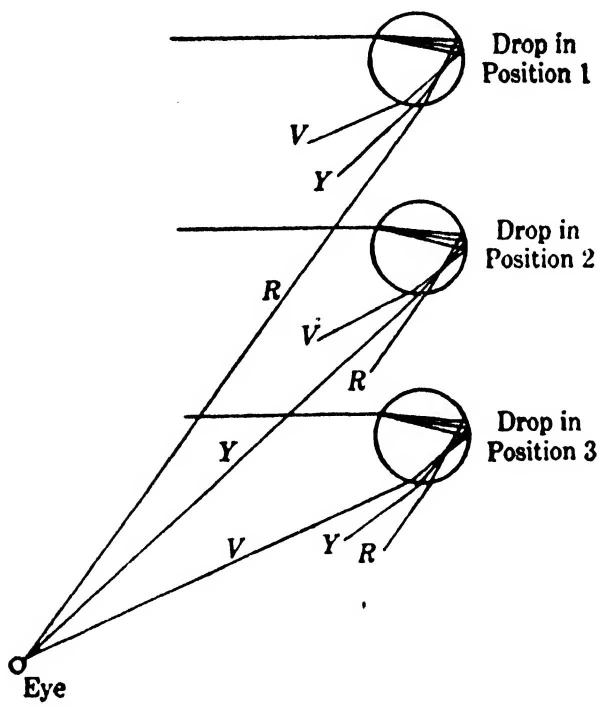


FIG. 182. How a rainbow is produced.

It is possible to see the entire circle of a rainbow from an airplane provided that the sun is behind the observer and the elevation is not too great.

Circles of light sometimes seen around the sun or moon are called halos. Halos are red on the inside and shade off to a pale yellow color on the outside. They are formed by the refraction of light by minute ice crystals.

The color of an object depends upon the wave length of the light which reaches the observer after the light has passed through or has been reflected from the object. Colored materials produce color by the absorption of all colors except the ones seen. White objects absorb less light than black objects.

Substances show their natural colors (*i.e.*, the colors which they exhibit in sunlight) only when illuminated by white light. When artificial light which is deficient in certain wave lengths is used to illuminate objects, those colors which are missing cannot be reflected. Thus a red cloth appears black in the light from a mercury-vapor lamp because this light does not emit red rays.

The Normal Eye Has Three Types of Color Receptors.

The ear can recognize a mixture of the different frequencies of sound, but the eye is incapable of analyzing the components of light. No one would ever guess that sunlight is a mixture of colors if it could not be separated into its component hues by prisms, raindrops, or other means. There are three types of receiver cells in the eyes. The sensation of color depends upon the relative responses of these three types of receivers to the light which enters the eye. If any one of these types of receiver cells does not function properly, color blindness is the

result. For instance, if the cells which are most responsive to red are lacking, there is difficulty in distinguishing red flowers from green leaves. A particular color sensation is due to the stimulation of the three receivers in the proper proportions.

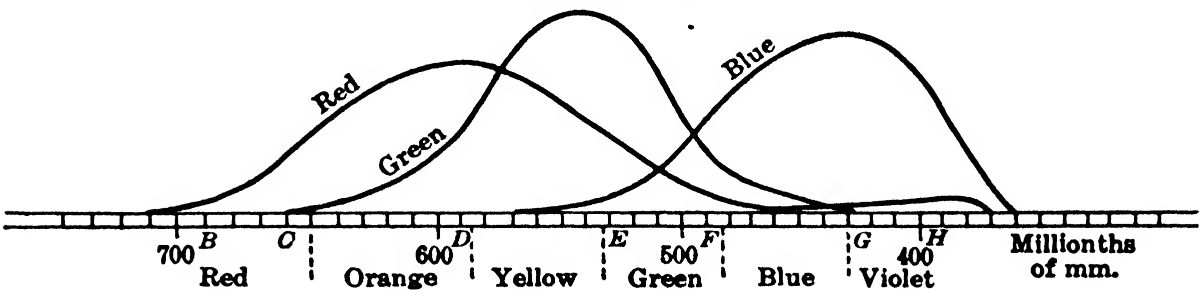


FIG. 183. The range of the three types of color receptors.

If one looks at a red color for some time, the red receptors become tired, and, as a result, when one turns away to look at a white surface, his eyes see a green afterimage because the red has been taken out of the white. Our eyes do not see all colors with equal ease; they see yellow much better than red or blue.

Materials Transparent to Certain Colors Produce Color by Subtraction.

A piece of red cellophane or red glass produces red light when placed in front of a white light because these materials are transparent only to the red rays, the rays of other wave lengths being absorbed.

If two screens, say a blue screen and a yellow screen, are placed one in front of the other, the only light transmitted will be green. Green is the only color common to the ranges of wave lengths which produce the sensations of yellow and blue in the eye.

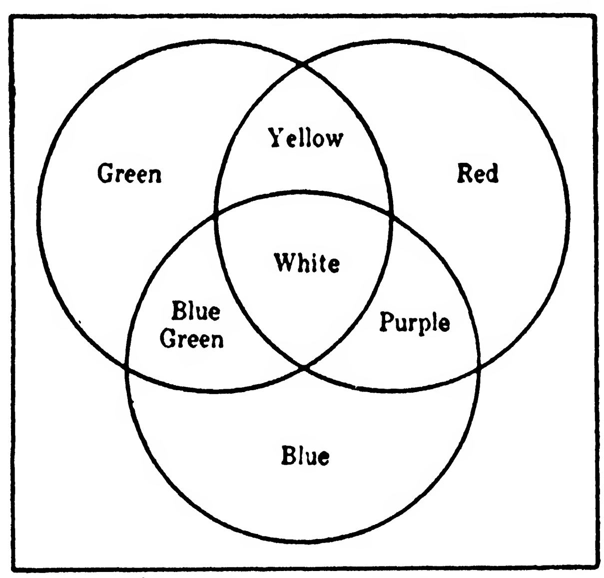


FIG. 184. Mixing additive colors.

A vast variety of colors may be produced by the use of three colored lights, red, green, and blue, which are called the additive primaries. Thus when red and blue lights are used to illuminate a white surface, an extensive series of purples ranging from reddish-purple to blue-purple may be obtained by varying the intensity of one or the other of the lights.

Pigments Produce Color by Resonance.

When white light shines on pigments, some rays are absorbed, and other rays are reflected. The color of a pigment is the result of a sub-

tractive process. A red pigment absorbs all but the red rays, which are reflected. A mixture of pigments of different colors reflects only those wave lengths which neither pigment absorbs. It is a common experience that in (the indiscriminate) mixing of pigments grays usually result, because combinations of pigments of several colors will absorb all of the wave lengths about equally.

The secret of the destruction of color by pigments lies in a principle known as resonance. Resonance is illustrated by the following examples:

1. One tuning fork, when vibrating, will set up vibrations in another tuning fork of like pitch.
2. A string in a piano will vibrate when one sings strongly the note corresponding to a key which is gently depressed to take off the damper.
3. Resonance is the foundation of radio reception. We turn the knobs of the receiving set until the frequency of vibration in the condensers and coils is the same as that of the wave system coming from the broadcasting station.

Pigments absorb colors of certain wave lengths in a comparable manner. The radio receiver absorbs long waves, while the pigment absorbs short waves.

A study of molecular structures in relation to color gives much information as to what part of a molecule acts as the receiver to cause the color. Certain architectural designs of molecules result in conditions conducive to the production of colors under proper exciting conditions.

The Primary Colors Used in Producing Colored Lights Are Not the Primary Colors Employed by Artists in Mixing Pigments.

The pigment primaries, reddish purple, yellow, and blue-green, are called subtractive primaries.

A green and red light when mixed will produce a yellow sensation by addition, but a blue-green and a purple-red pigment will produce a bluish-gray color because nearly all of the colors originally present are subtracted by the two pigments.

Colored Photographs May Be Transmitted over a Telephone Wire.

Colored photographs depend upon the use of the three primary colors, blue, red, and yellow, to produce all other colors. A colored picture may be produced by taking three pictures of an object, using films which are sensitive to blue, red, and yellow colors, respectively. These films may be combined as three different layers in one film and may then be selectively dyed, so that the finished film will transmit a

colored picture in a projector. The three films may be used to produce three different colored prints in gelatine films, which are then superimposed to produce a colored photograph. Or the three films may be used to produce three different photoengravings, the blue one being used with blue ink, the red one with red ink, and the yellow one with yellow ink, each color being superimposed on the other to produce the colored printing with which we are familiar.

In order to transmit a colored photograph over a telephone wire, the colored photograph is first broken down into three elemental prints, blue, red, and yellow. Three black-and-white negatives are made of these prints, and they are fastened with their axes in parallel on a drum, which is scanned by an "electric eye" line by line in a direction transverse to the parallel axes as the drum is rotated. The "electric eye" produces an electric current that fluctuates in correspondence to the shading of the prints. This electric current is transmitted over a telephone wire to the receiving station, where corresponding prints are produced by a similar scanning device that changes the fluctuating electric current into a fluctuating light. The three prints thus obtained are used to produce photoengravings for color printing.

Complementary Pigment Colors Produce Gray Light by Addition.

Complementary colors consist of pairs of colors which, when mixed, will give gray light. One method of determining complementary colors is based on the principle of retinal fatigue, mentioned above. If a circle of red paper, strongly illuminated by white light, is gazed at intently for about thirty seconds and is then replaced by a sheet of white paper, a bluish-green circle will appear to take the place of the red. The retina becomes fatigued by the red so that when acted on equally by all colors, it responds more strongly to the remaining colors in the spectrum. The red and bluish-green are complementary. Any one of the three primary pigment colors will produce its complementary color in the same manner. Complementary colors may also be determined by blending colors on a color wheel. Some other complementary color combinations are: orange and blue, yellow and blue-violet. In each of these cases the color is a primary color, and its complement is a result of a mixture of the other two primaries.

Blackouts May Employ Complementary Lighting.

By the use of complementary lighting, windows may be treated so that they will not permit artificial light to show through them at night but will permit the sunlight to shine through them in the daytime. The windows are covered with blue filters which will not pass

orange light, and lamps are used which give orange light free from blue light. Sodium-vapor lamps are satisfactory for this purpose. During the daytime, the orange light of the sun is absorbed by these blue filters, but the blue light is transmitted.

Hues, Tints, and Shades Are Color Terms Used in Art.

A hue is a color produced by one band of wave-length frequencies of the visible spectrum. A pigment hue is a pigment which reflects light of only one frequency or of a range of frequencies. The spectral colors, red, orange, yellow, blue, green, indigo, and violet, are hues. A practiced eye may be able to recognize about 230 spectral hues.

A tint is obtained by adding white to a hue; for example, pink is a tint obtained by adding white to red.

A shade is obtained by adding black to a hue or a pure color.

The relation of a hue to black or white is spoken of as *value* in art. The value is said to be lighter if white is added and darker if black is added.

The various colors of the spectrum may be arranged in the order of their natural color value, yellow being the lightest, and blue-violet being the darkest; this does not mean that black is present in the dark value or that white is present in the light value. Thus it is seen that value has a dual role in that it occurs in pure colors as well as in shades and tints.

Values should be close when combining colors; for example, tints or light values are combined with neutral values as accents rather than with black, because black is too strong a contrast. If black were wanted as the accent, middle values would be used for the general scheme.

Values are affected by the texture of the material on which they appear. The satin-backed crepe appears to be richer and darker on the satin side and duller and lighter on the crepe side.

Intensity is a term used to designate the strength of a hue as compared with gray. Intensity is a term used to refer to the purity of a hue as contrasted with the same color to which has been added one or more other colors; for instance, pure red is more intense than red orange. The intensity of a hue of a given value may be decreased by adding neutral gray. A neutral gray is one which is produced by the admixture of complementary colors. To neutralize a color, one grays it by adding its complement.

Colors May Also Be Produced by Interference.

The brilliant colors of the plumage of peacocks and other birds are not due to colored pigments but to the interference phenomena which are produced by thin transparent films on the feathers. Pearls, opals,

soap bubbles, tempered steel, and oil films on water produce colors in the same way. Interference in light corresponds to interference in sound, which is discussed on p. 461.

Colors May Also Be Produced by Scattering.

The colors of the sky are due to the scattering of light by molecules of the air and particles floating in the air, just as the waves of the sea are turned aside and scattered by rocks that rise above the surface. The short waves of light that compose the blue end of the spectrum are more easily turned aside than the longer, red waves, just as ripples are turned aside by a rock over which the larger waves heave themselves and steadily advance. Thus a separation takes place and color is produced.

For example, the smoke rising from a chimney looks blue against a dark background, especially if the smoke particles are quite small. If, on the other hand, the smoke is viewed against a bright background of luminous cloud or even against the sun itself, the color that comes through is brown or red.

A red light carries better than a white light in a misty atmosphere because the water particles do not scatter the long, red rays so much as they scatter blue rays. Hence infrared photography is valuable in a hazy atmosphere.

The setting sun and the rising full moon appear to be red because at the horizon the light has to travel a much greater distance through the atmosphere to reach the eye than it does when the sun or moon is directly overhead. The shorter blue waves are scattered, and only the longer rays toward the red end of the spectrum penetrate the great thickness of the atmosphere.

The color of the sky in the morning and evening is largely due to scattering of light by dust and water vapor. When Krakatoa exploded and ejected huge quantities of very fine dust into the air half a century ago, the colors of sunsets all over the world were strangely beautiful for many months afterward, because the dust drifted around the world and settled very slowly.

Cloud particles reflect all colors of the spectrum, and therefore reflections from the clouds show masses of shining white; but when clouds lie between us and the sun, they may intercept nearly all of the light and appear black.

Much of the blue color of the sea is due to the reflection from the sky. Under a leaden sky the sea looks gray. Near the shore the water is green because the fine sand in suspension reflects yellow, which is added to the blue light reflected from the sky.

Colors Are Used by Artists to Achieve Desired Effects in Accordance with Definitely Established Rules.

In painting a picture, selecting clothing, or decorating a home, one should follow the example set by nature. In nature brilliant hues are never present except in touches such as contributed by occasional flowers. Colors in nature harmonize with each other because they are mixed in varying proportions and thus prevent sharp contrasts. Nature employs green in large masses in the spring, but these greens are of many values and vary from yellow-greens to blue-greens. As other colors develop, these greens become darker and grayer and

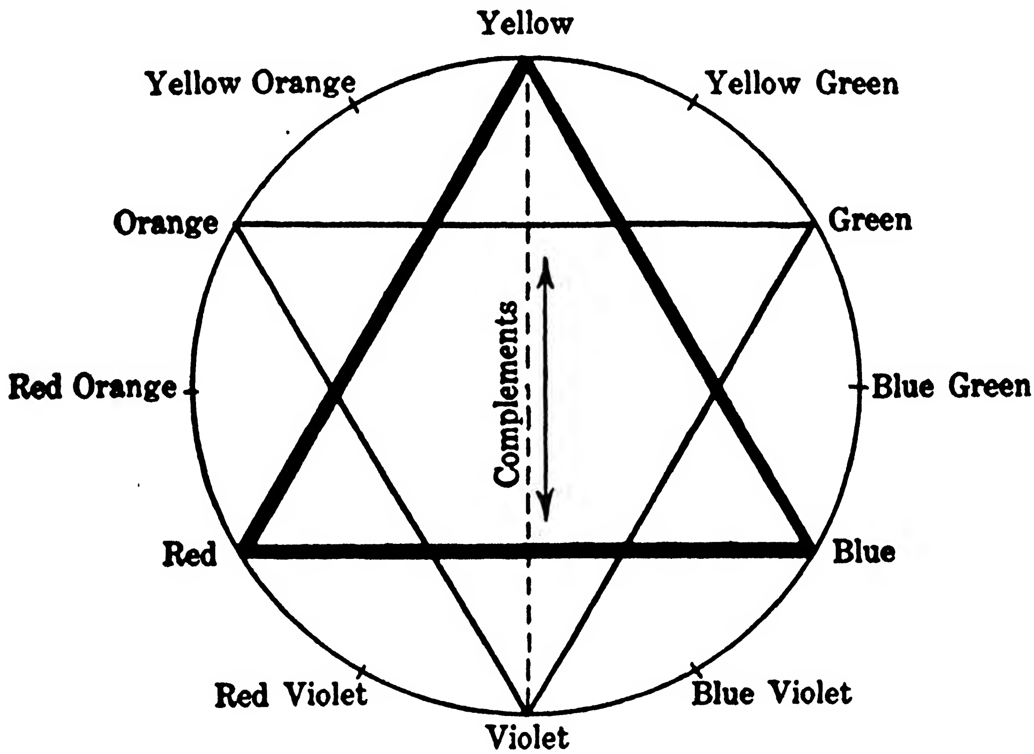


FIG. 185. The color circle. Place an equilateral triangle anywhere on the color circle to obtain colors which will harmonize with each other. When using pigments, the colors at opposite positions on the color circle are complementary colors.

gradually change to browns until in the fall the orange, red, and yellow colors of the flowers and colored leaves blend in with the browns in the background. Red is never found in masses in nature along with green masses but only in touches on butterflies, wings of birds, flowers, and fall leaves.

When one rotates an equilateral triangle within a color circle, the points of the triangle will indicate the colors which will harmonize with each other. When using pigments, the directly opposite colors on the standard color circle are complementary.

Red, yellow, and blue are primary colors, while orange, green, and violet are secondary colors — they are called secondary because they

consist of mixtures of two primary colors. Tertiary colors are those made by mixing a primary color with a secondary color.

Colors produced by mixture are more likely to be pleasing than pure colors used next to each other, which may produce too sharp a contrast. Expressed in another way, mixed colors are likely to be more subtle.

A general rule when using any primary color is to use with it the colors on either side of its opposite to produce a softer effect; for example, good harmonies might be produced by using yellow, orange, and red-orange; the complementary colors produced by interference using polarizing screens always harmonize.

In advertising, primary colors are used in large amounts next to each other in order to obtain attention. If you want to attract the attention of everyone who sees you, try wearing a yellow hat, with red pants or skirt, and a green coat.

There is a symbolism in color usage that is due in part to association and in part to sensation. Red lights signify danger and are associated with stimulation and excitement. Orange and brown are associated with warmth. Yellow is light, while blue is thought of as a cold color. Warm colors are said to be advancing while cool colors are receding; for example, in a landscape the foreground is warm, and the background is cool. Red, orange, and yellow are advancing colors, while violet, blue, and green are receding colors. Weight is indicated by dark values, while light values suggest less weight. *The smaller the area the brighter the color* is a statement of the *law of areas in colors.*

STUDY QUESTIONS

1. Describe two methods of producing the spectrum.
2. What is meant by diffraction of light?
3. Why do prisms refract light?
4. Explain how the eye sees different colors.
5. What is meant by complementary colors?
6. Why does a red light carry better than a white light in a misty atmosphere?
7. What is the source of color in an object?
8. Why does the eye see green when white light is viewed after looking at red light for a short period of time?
9. How do pigments destroy color?
10. Discuss the causes of the color of the sky and clouds.
11. Explain rainbows. How is a secondary rainbow produced? Do you think that it would be possible to produce a tertiary rainbow, and if so, how?
12. Explain the formation of halos.
13. How are colors of soap bubbles produced?
14. Although kerosene is a colorless liquid, a trace of it on the surface of a pool of water will give a variety of colors. How are these colors produced?

15. Why do colors in nature harmonize?
16. Give some general rules for the use of colors.
17. How may sharp contrasts be obtained by the use of colors?
18. What are primary and secondary colors?
19. What colors will harmonize with yellow? With green?
20. Why does a mixture of paints generally produce a gray color?
21. Explain color blindness.
22. List all the methods for the production of color that you can think of.
23. Differentiate between additive and subtractive primary colors.
24. Differentiate between primary colors and complementary colors.
25. Explain the colors of a sunset.
26. Why does the ocean water seem to be so blue?
27. Why does the blue color of the ocean disappear on a cloudy day?
28. Explain the beautiful green water of the Hawaiian shore line.
29. Discuss the color harmonies in nature at each season of the year.
30. Explain why it is difficult to match colors in artificial light.
31. What color is produced when yellow and blue pigments are mixed? When yellow and blue lights are mixed?
32. Work out a hypothesis to explain the following data:

    Unsterilized milk placed in colored bottles and exposed to the sunlight remained sweet the longest when placed in red bottles and soured the quickest in bottles having colors toward the violet end of the spectrum.

UNIT VI

SECTION 4

THE INVENTION OF POLARIZING-SCREENS PUT POLARIZED LIGHT TO WORK

Introduction.

The first recorded discovery of polarized light was made by *Bartholinus* of Denmark in 1670, who observed that an object viewed through Iceland spar appeared double. Bartholinus reasoned that the crystal separated the light into two beams. The later discovery of the physicist, *Nicol*, that Iceland spar crystals could be cut at certain angles and cemented together with Canada balsam to form prisms that would eliminate one of the above two beams of light made possible the polarimeter and polarizing microscope and thus harnessed polarized light for laboratory use.

In 1852 *W. D. Herapath* discovered that quinine iodosulfate crystals would polarize a beam of light, but he did not succeed in mounting them in a satisfactory manner. It was the discovery of *Edwin H. Land*, publicly announced in 1934, that these crystals could be suspended in a plastic cellulose acetate film and aligned by stretching the film, which made possible the polarization of light economically on a large scale.

Polarized Light Is Light Vibrating in One Plane Only.

Light waves are transverse waves, that is, they vibrate at right angles to the direction that the light is traveling, just as waves set up in a pool of water by a stone thrown into it travel at right angles to the up-and-down direction in which the water surface moves. Ordinary light is a mixture of transverse vibrations in all possible directions. When light is vibrating in one plane only, it is said to be ***plane polarized***, or just ***polarized***.

Light May Be Polarized by Double Refraction in Crystals.

Light may be polarized by passing it through crystals of certain substances such as Iceland spar or tourmaline. When a piece of Iceland spar is placed over a dot, two dots are seen through the crystal because

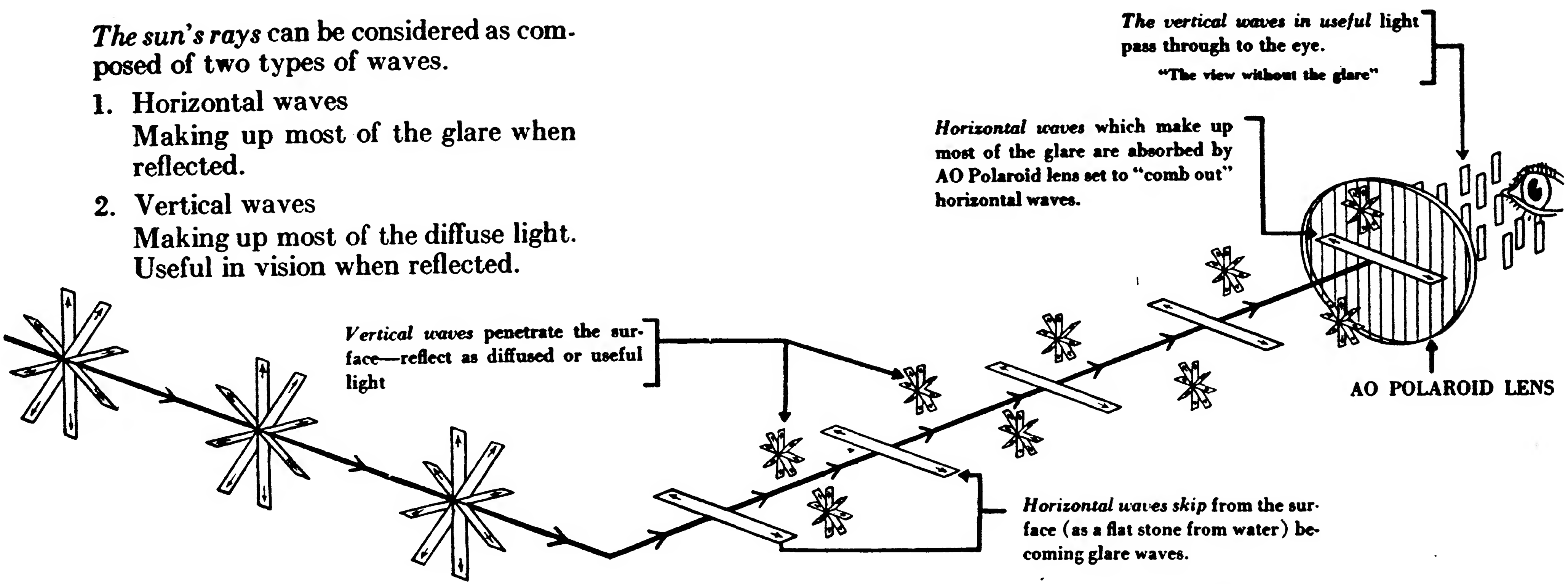


FIG. 186. The nature of polarized light. (Courtesy of The Polaroid Corporation.)

the crystal is doubly refracting. When light passes through an Iceland spar crystal, it is split into two perpendicularly polarized beams. In the case of tourmaline, one of these beams is absorbed completely while the other one is only partially absorbed, so that the light obtained is polarized. One can prove this by the following experiment: Place a Polaroid disk (described below) over the calcite crystal and rotate the disk. One dot will disappear, and as the polarizer is further rotated, this dot reappears and the other dot disappears. There is very little absorption of light as it passes through the Iceland spar crystal. When light passes through a Nicol prism, only one of the beams of polarized

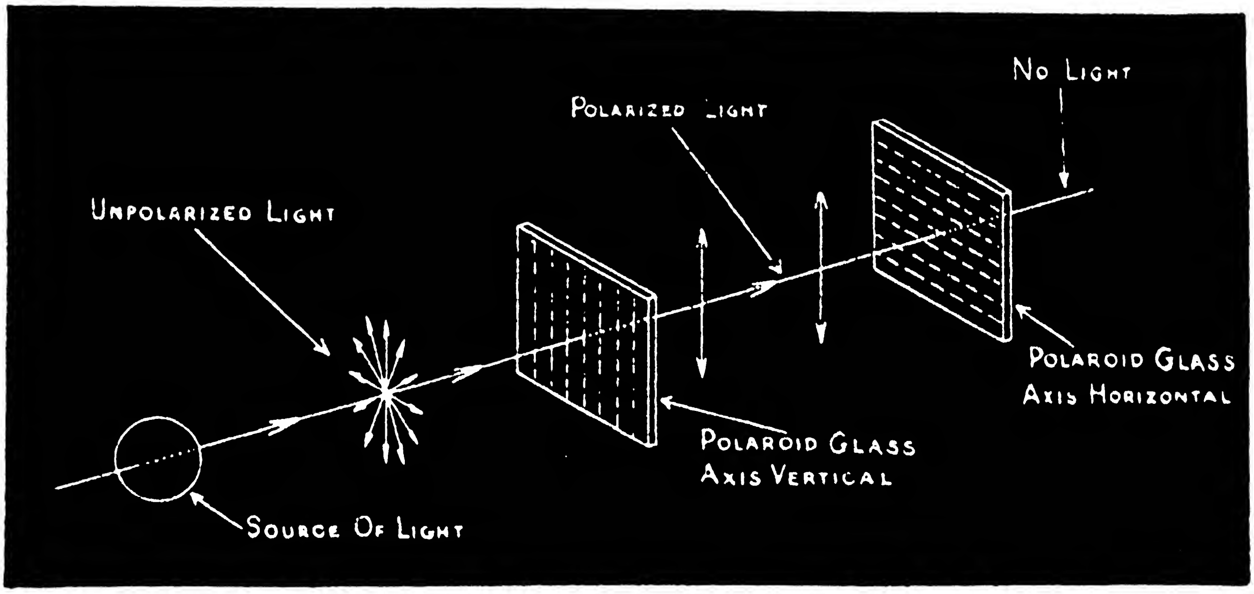


FIG. 187. The principle of the Polaroid screen. (Courtesy of The Polaroid Corporation.)

light gets through. Nicol prisms are used in polarimeters, which are instruments in which the amount of the rotation of the plane of polarized light as it passes through certain liquids or solutions is measured. Polarimeters are used to measure the concentration of certain sugar solutions inasmuch as the degree of rotation is proportional to the concentration of the solution.

The new type of polarizing medium called Polaroid, mentioned in the introduction to this Section, has made possible widespread applications of polarized light. A Polaroid screen consists of microscopic quinine iodosulfate crystals closely packed in a transparent cellulose plastic that is stretched before it solidifies, thus causing the crystals to be oriented end to end and providing optical slots through which light which is vibrating in only one plane may pass.

In 1941 *Edwin Land* produced a new polarizing medium, which uses individual molecules rather than crystals. The new polarizing sheets are produced by stretching heated polyvinyl alcohol plastic, thus aligning the plastic molecules, and then allowing the plastic to imbibe

an iodine solution. This new screen transmits one-third more light than the previous Polaroid screen and polarizes 99.99 per cent of the light to which the eye is most sensitive.

Light May Also Be Polarized by Reflection.

When light strikes a glass plate at an angle, about 5 per cent of the light is reflected, and a portion of this reflected light will be polarized. A pile of glass plates not only produces polarized light by reflection but polarizes the transmitted light much as crystals do. The angle of a glass plate or mirror relative to the direction of the beam of light determines the relative amounts of ordinary reflected light and plane polarized light. The best angle, called the angle of polarization, is about 57 degrees for ordinary glass.

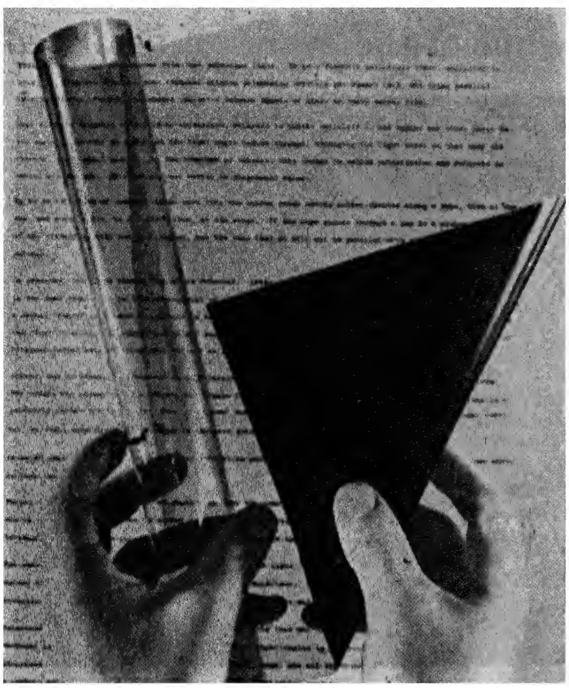


FIG. 188. You can see perfectly through several thicknesses of Polaroid if their "optical slots" are parallel, as they are in the roll at the left. But when the "slots" of the material are crossed, as they are in the fold at the right, no light passes and you cannot see through. (Courtesy of The Polaroid Corporation.)

Direct glaring reflections of sun and sky from the sea and asphalt or concrete pavements are polarized to a fairly high degree, while the diffuse reflections used in vision are not. By using a polarizing sun glass, it is possible to block the glare while transmitting the useful light.

Light May Be Extinguished by Use of Crossed Polarizers.

Figure 187 shows how a second Polaroid disk placed perpendicular to the axis of the first Polaroid disk will not permit the light which is polarized by the first disk to pass through the second disk.

Figure 189 shows how the use of polarizing screens on headlights and windshields would eliminate automobile-headlight glare.

Inasmuch as nearly 60 per cent of light is absorbed when it passes through a polarizing screen, headlights would have to be two or three times as powerful as present headlights when using polarizing screens. The benefits of polarizing screens would be proportional to the number of cars equipped with them.

Each car is fitted with a windshield visor of Polaroid, with its "slots"

arranged at an angle of 45° to the ground in one proposed system of eliminating automobile-headlight glare.

The headlights of each car are fitted with Polaroid lenses with their slots parallel with the visor slots, that is, at exactly the same angle. The light from the headlights strikes the road and is reflected back through the Polaroid visor to the driver, who gets the benefit of his own headlights because the visor and headlight slots are parallel.

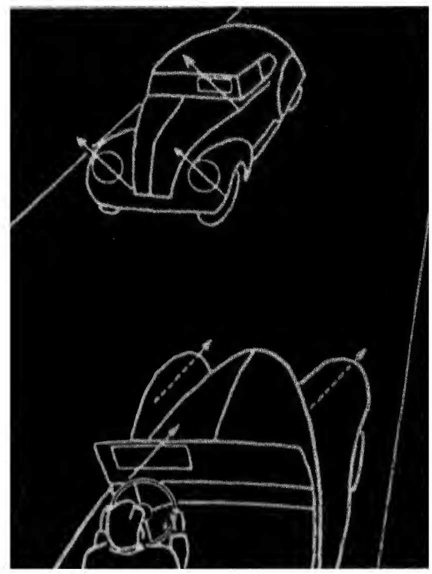


FIG. 189. Polaroid visors used to eliminate headlight glare. (Courtesy of The Polaroid Corporation.)

When two cars thus equipped meet each other, neither driver sees the direct light of the approaching headlights because the slanted slots of the Polaroid are crossed at right angles inasmuch as the cars are facing each other. Light from the approaching car cannot get through the visors, and glare is therefore eliminated.

Light May Be Polarized by Scattering.

When light is reflected from particles such as the drops of moisture in the clouds, there is no polarization; but when light is reflected from much smaller particles, such as dust and smoke particles, the light is scattered, and a bluish tinge typical of desert scenery appears. These small particles scatter short waves better than long ones; the blue waves are on the shorter-wave-length end of the visible

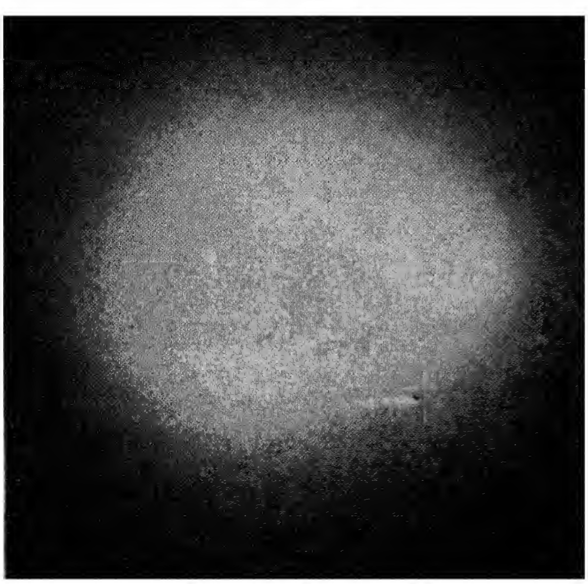


FIG. 190. Unretouched photographs. Left, ordinary headlights. Right, Polaroid headlights through a Polaroid visor. (Courtesy of The Polaroid Corporation.)

spectrum. Under these conditions the light scattered in any direction perpendicular to the light beam is polarized. The sky is blue due to

FIG. 191. Left, without Pola screen. Right, Pola screen darkens the sky because the light from the direction at right angles to the sun is partially polarized. (Courtesy of The Polaroid Corporation.)

this scattering effect, and the clearer the air is the bluer the sky is, because it is the smaller air molecules rather than the larger dust particles that are scattering the light. Remember that the smaller

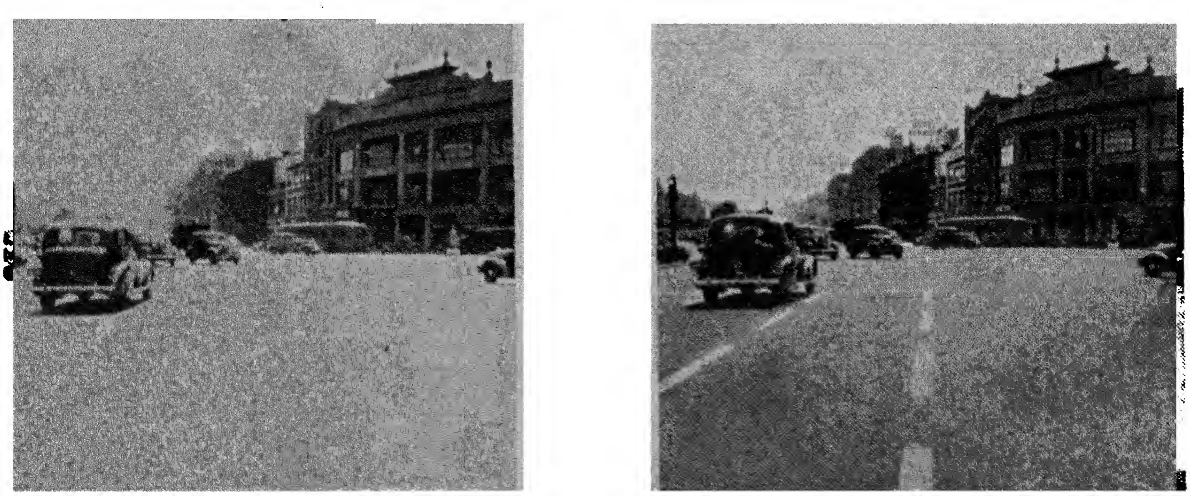


FIG. 192. Left, unretouched photograph through ordinary anti-glare glasses. Right, simultaneous photograph identical exposure through Polaroid glasses. (Courtesy of The Polaroid Corporation.)

the particle, the shorter will be the wave length of the light that is scattered. The light in the direction perpendicular to the rays of the sun is almost completely polarized in very clear air.

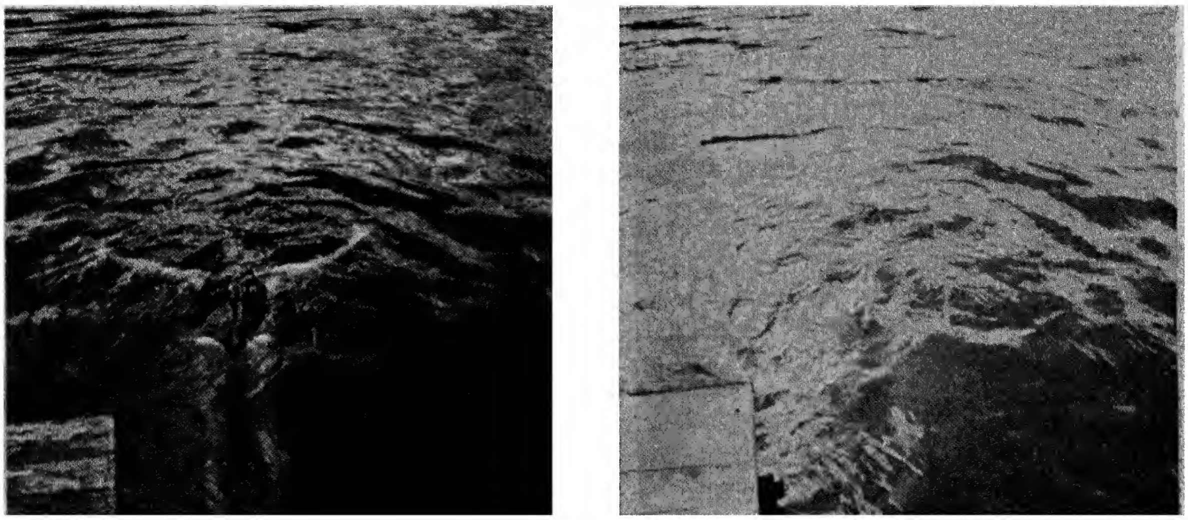


FIG. 193. Right, through ordinary sun glasses. Left, through Polaroid day glasses. (Courtesy of The Polaroid Corporation.)

Figure 191 shows how the polarized light from the sky was intercepted by use of a Pola screen over the camera lens. The use of such a screen eliminates the glare in photographing such scenes as lakes and streams, store windows, and streets.

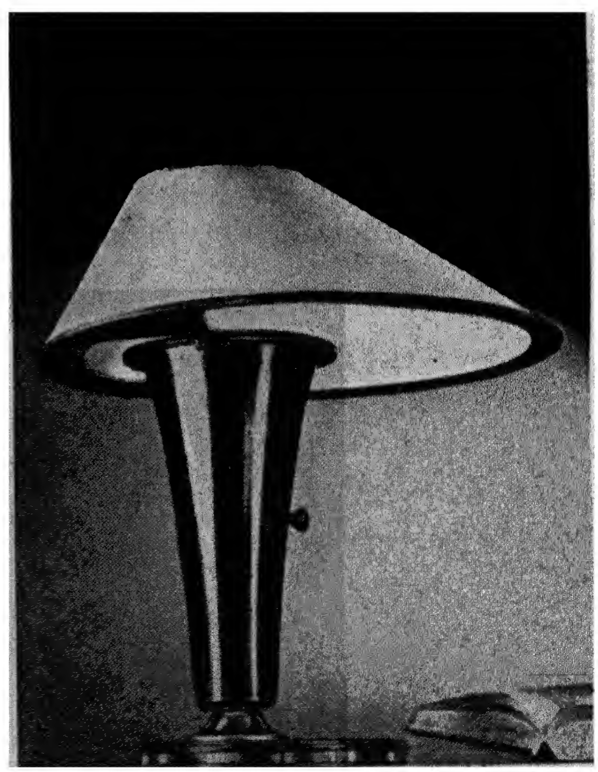


FIG. 194. A desk lamp delivers its light through a Polaroid filter, thus suppressing the glare on the working surface. (Courtesy of The Polaroid Corporation.)

Polaroid Day Glasses Eliminate Glare.

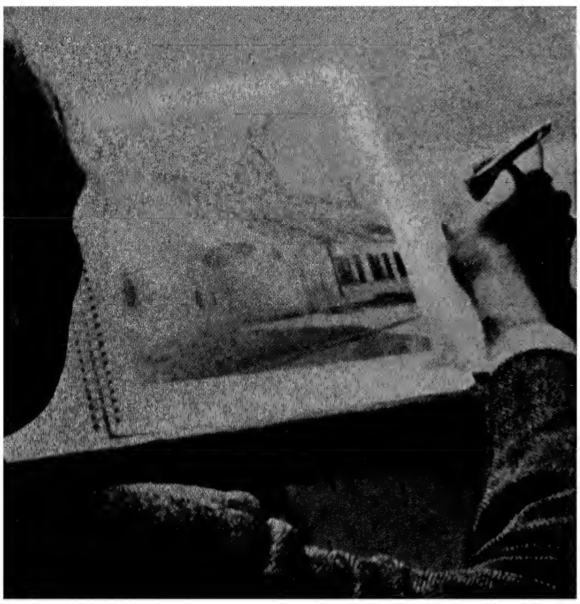
Ordinary sun glasses reduce the intensity of glare, but at the same time they reduced the intensity of the useful, reflected, diffuse light. Polaroid glasses allow the reflected diffuse light to pass through but cut out the reflected glare light which is highly polarized. Inasmuch as polarized light is reflected usually from horizontal surfaces, the horizontal vibrations predominate in polarized light, and a Polaroid screen placed in a vertical position will intercept the polarized light.

Figure 192 shows the extent to which Polaroid glasses remove glare.

Polaroid glasses eliminate the glare from water, sand, sundecks, snow, and ice.

Polaroid Lamps Provide Glareless Illumination.

By passing light through a polarizing screen whose polarizing axis is vertical and at the proper angle relative to the table top, a glareless reading lamp has been made possible.



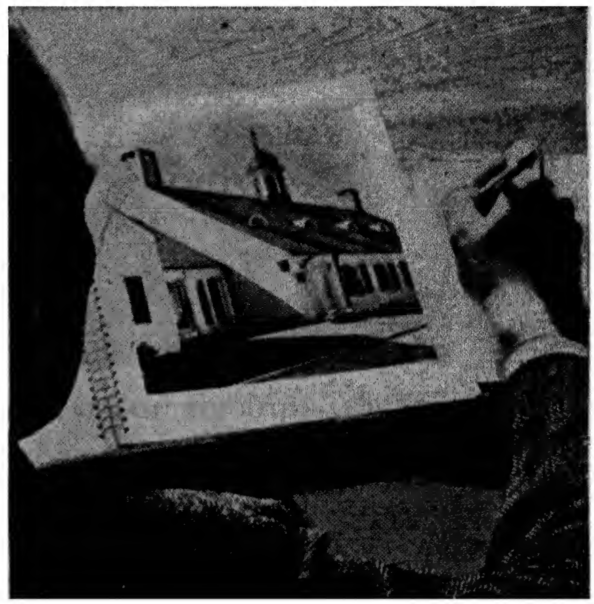


FIG. 195. Left, photograph made with ordinary desk lamp. Right, photograph made with a polarizing desk lamp. (Courtesy of The Polaroid Corporation.)

Beautiful Color Effects Are Produced by Interference of Polarized Light.

If a sheet of cellophane, mica, or cellulose tape is placed between two polarizers so oriented that the light is eliminated, beautiful color effects will be produced. The production of color by this method offers excel-

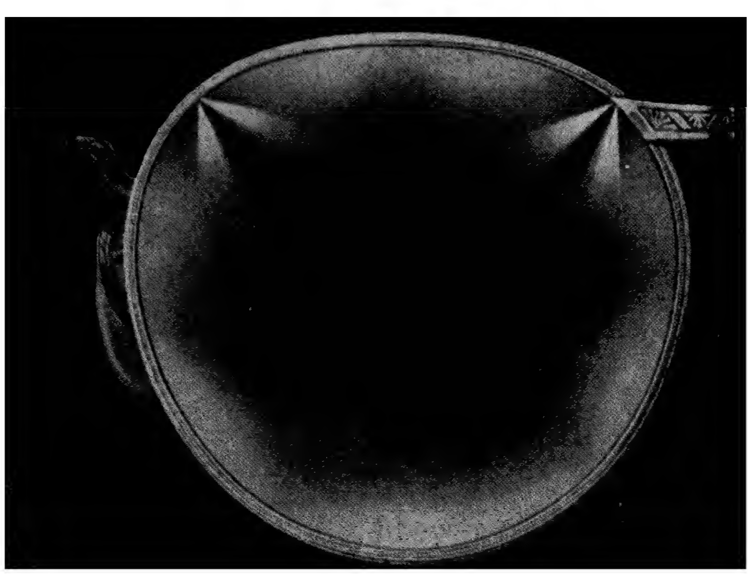


FIG. 196. Strains revealed by polarized light. (Courtesy of the American Optical Company.)

lent possibilities for illumination of stages, ballrooms, floodlighting, and colored advertising displays.

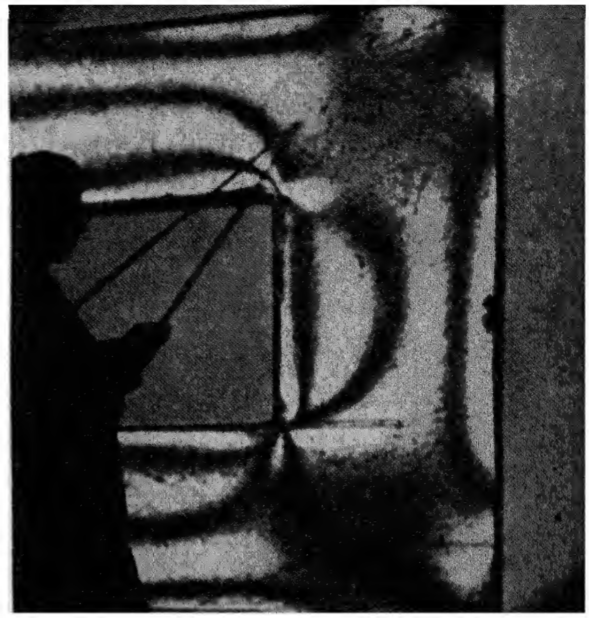


FIG. 197. A "map" of the stress distribution appears in transparent plastic models under load. (Courtesy of The Polaroid Corporation.)

Polarized Light May Be Used to Study Strains in Transparent Materials.

By flexing a piece of transparent plastic material between two crossed polarizing screens through which a beam of light is passing, colored interference patterns will become visible. Strains in optical glass, radio tubes, mounted lenses, and glass apparatus may be detected by use of polarized light in this way. Such strains may result from poor annealing of glass. Glass which is poorly annealed is likely to crack when subjected to sudden temperature changes that would not crack glass free from strains. Gears, miniature bridge members, etc. may be made out of transparent plastic materials and then tested while placed in a beam of light between crossed polarizers. Such experiments enable engineers to determine the points of greatest strain under varying conditions.

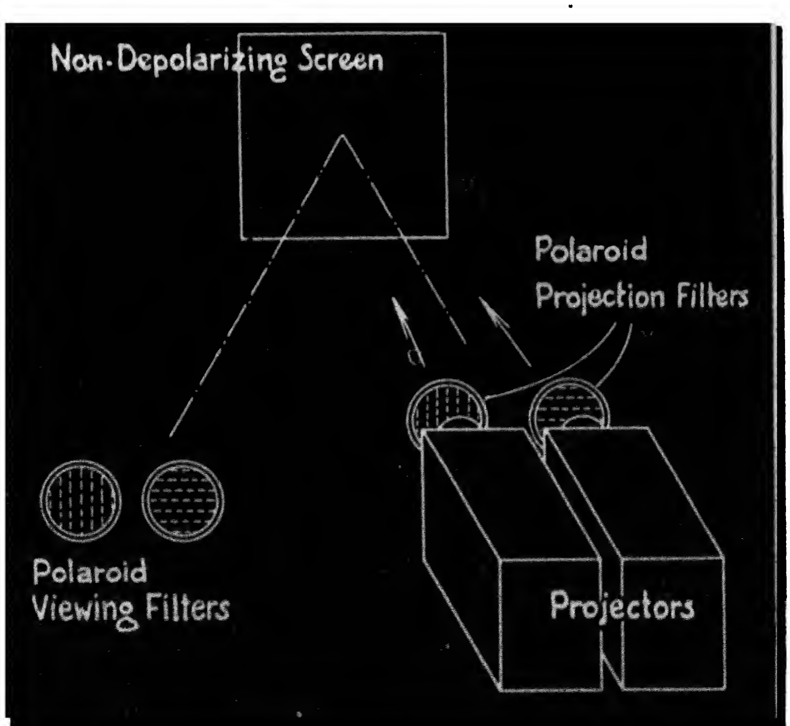


FIG. 198. The principle of the three-dimensional motion pictures using Polaroid filters. (Courtesy of The Polaroid Corporation.)

Three-dimensional Pictures Are Made Possible by Polarizing Screens.

Polarizing screens have made possible the projection of three-dimensional (stereoscopic) still and motion pictures both in black and white and full color. Two nearly, but not quite, identical pictures taken with a "two-eyed" camera having the lenses separated by the distance between the human eyes, are projected one over the other, one in horizontally polarized light and the other in vertically polarized light. The viewer wears Polaroid spectacles in which the axes of the lenses are at right angles to each other, so that one eye sees only one picture, while the other eye sees only the other picture.

Fig. 199. Control of light in a modern streamliner train by means of a Polaroid screen. (Courtesy of The Polaroid Corporation.)

Polarized Light Is Used in Peace and War.

When the eyes of soldiers attempt to penetrate the glare of the sky in search of enemy dive bombers, when the sea is scanned for submarines, the sheeting that screens polarized light will prove useful. In gun sights, periscopes, range-finders, telescopes and in dozens of other ways, polarized light will be made to serve the military machine we are building.

Polarized light, applied to eye examinations, has trapped persons who falsely claimed damaged eye sight in order to collect insurance. One young woman claimed that one of her eyes was damaged in an accident. The examiner gave her a pair of polarizing glasses with the planes of polarization of the two lenses at right angles to each other. She was asked to read from one of those scrambled alphabetical charts that eye doctors use. The trick in the examination was to first project the charts on a screen with vertically polarized light and then quickly switch from vertically to horizontally polarized. This means that the image can be seen by only one eye at a time. When the woman kept reciting as the illumination changed from vertically to horizontally polarized light, it proved conclusively that she was

seeing equally well through both lenses and, therefore, with both eyes. Her $50,000 claim for damages was thrown out of court.

Crack railroad trains speeding over western plains are light-conditioned as well as air-conditioned. Light conditioning is made possible by windows of two polarizing discs with flat surfaces against each other. They are mounted in such a way that the outer disc is set stationary to block all reflected glare while the inner disc can be moved by turning a knob, whenever the passenger wants to reduce or increase the amount of light that enters the car. Exactly the same principle is used in new variable sun glasses which enable the wearer to reduce the brilliance of a scene simply by touching a button on the glasses.[1]

STUDY QUESTIONS

1. What is polarized light?
2. In what three different ways may light be polarized?
3. What is a Nicol prism, and for what is it used?
4. What is the nature of a Polaroid screen?
5. Explain how the glare from streets, snow, sand, or water is removed by Polaroid screens.
6. Explain how the glare from automobile headlights could be removed by the use of Polaroid screens.
7. Why are the axes of the visor and the headlights in the polarized-light system proposed for automobiles arranged parallel and 45° to the road?
8. Explain why the blueness of the sky depends upon the clarity of the air.
9. How can one prove that the light scattered by the molecules of the atmosphere is polarized?
10. Explain how the intensity of light may be controlled by the use of Polaroid screens.
11. Why do Polaroid day glasses intercept the glare from only horizontal surfaces?
12. What are the advantages in the use of Pola screens in photography?
13. Explain the use of polarized light in detecting strains in transparent materials.
14. Explain how three-dimensional pictures are made possible by Polaroid screens.
15. Show how polarized light was used to trap a woman who falsely claimed damaged eyesight.

[1] From *Science News Letter*, November 9, 1940, p. 294.

UNIT VI

SECTION 5

LIGHT MAY BE REFLECTED AND REFRACTED

Introduction.

The reflection and refraction of light have many important applications today. Many of our most important scientific instruments, such as the telescope and the microscope, depend upon these properties of light.

A Few Terms Used in Connection with the Propagation of Light Are Defined.

Light travels through space without loss of energy, but when it travels through matter such as water or glass, a small amount of energy is absorbed; such materials are said to be *transparent.* Some materials, like frosted glass, which scatter most of the incident light, are said to be *translucent.* Other materials, like wood or stone, which transmit no light, are said to be *opaque.*

When light is thrown back upon striking a surface, it is said to be *reflected.* The ray striking the surface is called the *incident* ray, and the ray leaving the surface is called the *reflected* ray. That portion of light which is lost when a beam of light passes through a transparent medium or when it is reflected from a medium is said to be *absorbed.* Light which is absorbed is changed into some other form of energy such as chemical energy, electrical energy, or heat energy. When light changes its direction as it passes from one medium to another, it is said to be *refracted.* When light strikes the edge of a body or passes through a small aperture, the light does not cast a sharp shadow because a portion of the light deviates from its course, *i.e.*, it spreads out. This spreading-out of light is called *diffraction.* The *diffusion,* or *scattering,* of light is different from diffraction in that it is the result of multiple reflections from rough surfaces.

Light Travels in a Straight Line.

Light travels in a straight line in a vacuum or in any homogeneous transparent medium. The path of a projector light in a smoke-filled

theatre demonstrates the path of light by the illumination of the smoke particles which the air contains.

The Reflection of Light Has Some Interesting Modern Applications.

Some objects, such as incandescent lights, are luminous and are themselves the sources of the light which reaches the eye; but the majority of objects are visible only because of the light which they reflect to the eye.

A perfect mirror would reflect all of the light falling upon it and would in itself not be visible, while a rough surface reflects some of the light and absorbs some of the light which falls upon it. The reflected light is reflected from the rough surface in many directions and is thus diffused. Under such conditions the surface becomes visible.

When a ray of light strikes a mirror, it will be observed that the incident and reflected rays make the same angle with a line perpendicular to the mirror at the point of incidence. This is the fundamental law of reflection. If two mirrors are placed at right angles to each other, the rays will be reflected in a line parallel to that in which they came, regardless of the angle at which the incident rays reach the first mirror.

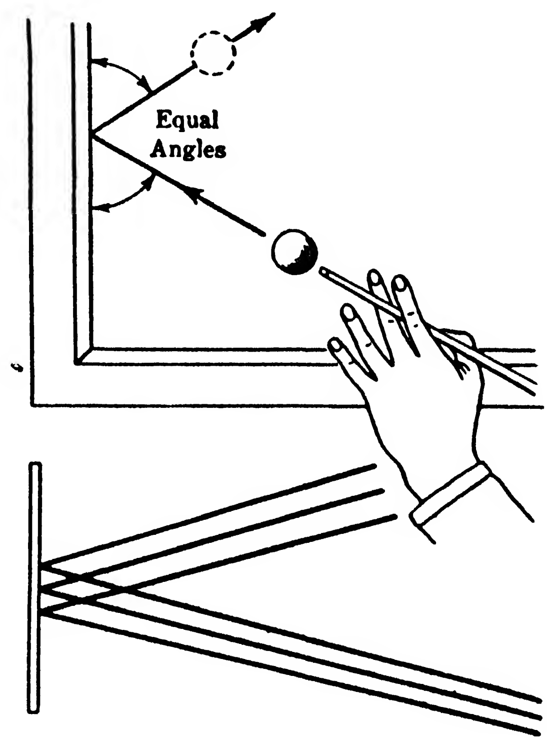


FIG. 200. The angle of incidence equals the angle of reflection. (From *Optics and Wheels*, Courtesy of the General Motors Corporation.)

If three mirrors are placed perpendicular to each other, as shown in Fig. 201, all light rays will be reflected back in the direction from which they came, regardless of how the combination of mirrors is held.

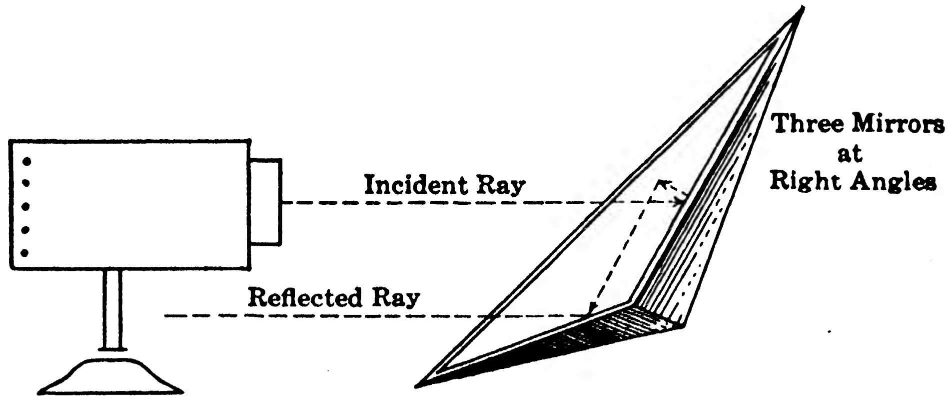


FIG. 201. Reflection from three mirrors at right angles. The entering and returning rays are parallel, regardless of the position of the mirrors relative to the direction of the rays.

The success of signal buoys at sea and the red and white reflectors now used so widely on bicycles, signs, guard rails, and house numbers depends upon this principle.

There are two taillights on modern automobiles, which enable one to judge how far ahead a car is at night. If the lights appear to be close together the car is far ahead, but if they spread apart rapidly you are approaching the car ahead at a fast rate of speed.

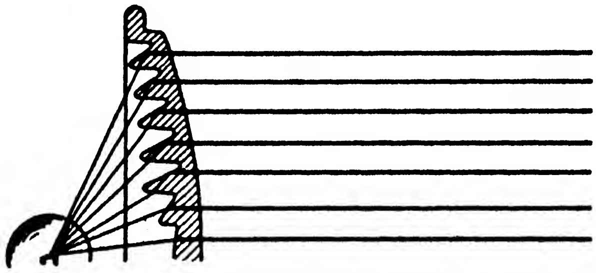


FIG. 202. Beam from a reflex reflector type of taillight.

Modern taillights have sections (reflex reflectors) which will reflect the light from a car behind if the taillight bulb burns out.

The sky would appear black if it were not for the fact that the molecules and dust of the atmosphere diffuse the light of the sun and moon by reflecting a portion of the light. It can be shown that it is the dust particles that are responsible for this diffusion of the light of the sun which causes the changing colors at sunrise and sunset, because, when light is passed through a dust-free box, it is invisible although it can be seen before it enters and after it leaves the box; light cannot be seen unless it is coming toward one. Thus a powerful beam of light from a searchlight could be passed through a dust-free room and leave it in complete darkness. The room would be illuminated at once, however, by placing a white object in the path of the light. A useful application of this idea is the placing of a white or light-colored object in front of an automobile to reflect the light from the headlights when one is caught with engine or tire trouble without a flashlight on a dark night.

The images of objects in flat mirrors differ from the original only in that they are reversed. Mirror-writing is a common example of this effect.

Invisible Glass Has Many Practical Uses.

C. Hawley Cartwright discovered that a film of magnesium fluoride placed on glass makes it invisible by rendering it nearly perfectly transparent. Ordinary glass reflects about 8 per cent of the incident light and transmits about 92 per cent, while this new coated glass transmits 99.6 per cent of the incident light. For the films to be rugged enough to be practical in most cases, the transmission is increased to only 98 per cent. Reducing the reflection 5 per cent for each surface, however, reduces glare and ghosts 25 per cent.

This invention promises to have widespread application in eliminating the glare from showcases, store windows, and glass-covered paintings.

It has already been applied in making camera lenses "faster." This "speeding-up" of lenses is especially valuable in color photography and television.

The thickness of the film is four millionths of an inch, and it must be carefully controlled because the secret of the success of the film depends upon its thickness. A film of this thickness is such that the light rays reflected by the two surfaces of the film cancel each other by interference.

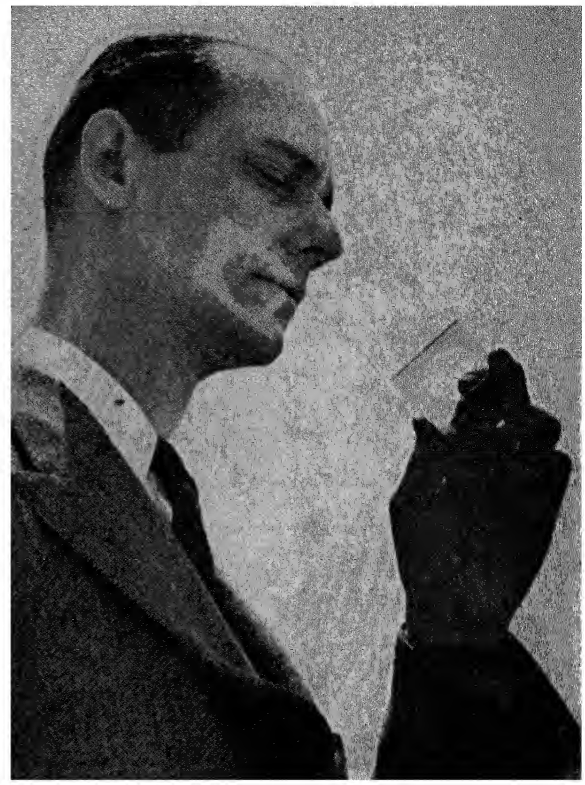


FIG. 203. This reflection on the face of C. Hawley Cartwright shows how a thin film decreases the light reflection from glass. Sunlight is reflected from the glass to his cheek. The round spot in the center of the piece of glass was coated with a thin film of magnesium fluoride. (Courtesy of Science Service.)

Concave and Convex Mirrors Are Used Like Lenses to Focus or Diverge Light.

Mirrors of curved shape are used as reflectors in automobile headlights. Light from a distant object will be brought to a focus at the point where the lamp is located. This is the principle of the reflecting telescope, flashlights, and parabolic reflectors of automobile headlights. On the other hand, an automobile lamp placed at this point of focus will reflect long parallel beams.

Concave mirrors can produce three kinds of images depending upon the position of the object: (1) if the object is very close to the mirror, the image will be upright but larger than the object — dentists' exploratory mirrors use this principle; (2) if the object is placed somewhat farther from the mirror, the image will be smaller than the object and

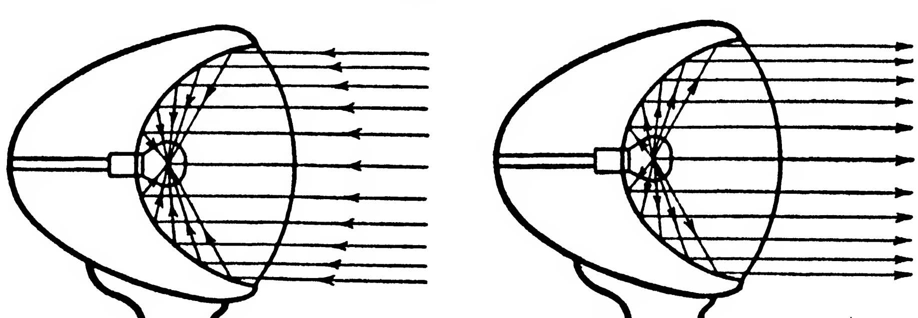


FIG. 204. In the automobile headlight the lamp is placed at the focal point of the concave mirror.

inverted; (3) if the object is placed still farther away, the image will still be inverted, but it will be larger than the object.

The bowl of a spoon or the side-rear-view mirror of an automobile are convex mirrors, in which the image is always smaller than the object.

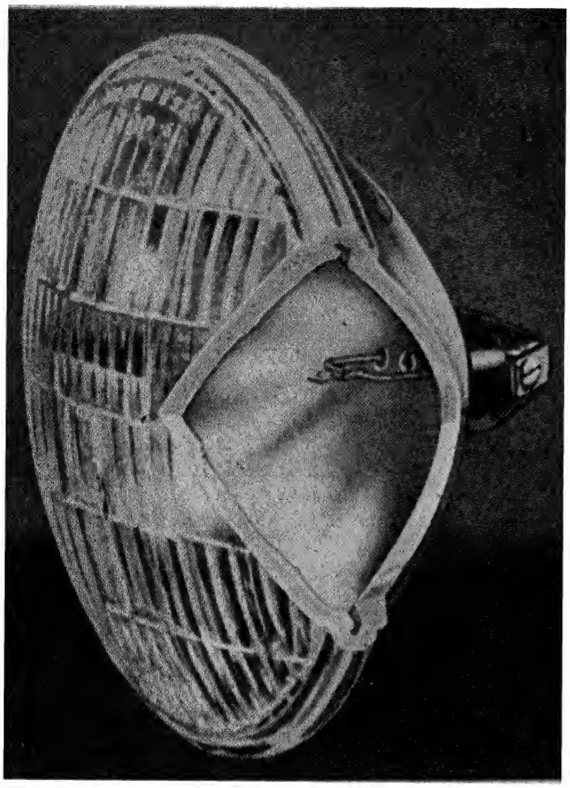


FIG. 205. An all-glass driving lamp, similar in construction to a sealed-beam headlight except that it employs one filament instead of two filaments. (Courtesy of the General Electric Company.)

Sealed-beam reflectors were introduced on automobiles in 1940. These headlights seal the interior from dust and moisture and thus preserve the reflecting surface. One type of sealed-beam headlight uses a silver-plated brass reflector, a lamp, a glass lens, and a gasket, while a second type uses a glass lens fused to a glass reflector filled with argon gas in which the lamp filaments are located without the use of a separate bulb.

The use of offset filaments in an automobile headlight controls the beam in the two-beam headlight system. See Fig. 206. By placing one filament slightly to the side of the other, the beam that tilts down also turns somewhat to the right. See Fig. 207.

The Refraction of Light Explains Many Phenomena.

The velocity of light is different in media of different densities. A crucial test of the two theories of light was based on this fact. Accord-

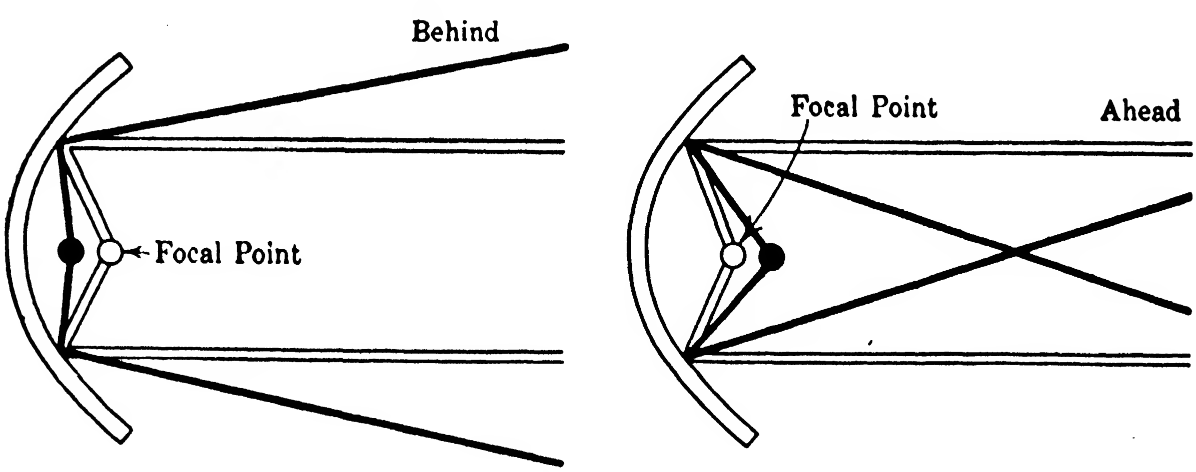


FIG. 206.

ing to Newton's corpuscular theory, light would travel through water with a greater velocity than it would travel through air, and the reverse would be true of light if propagated by waves. In 1850 the French

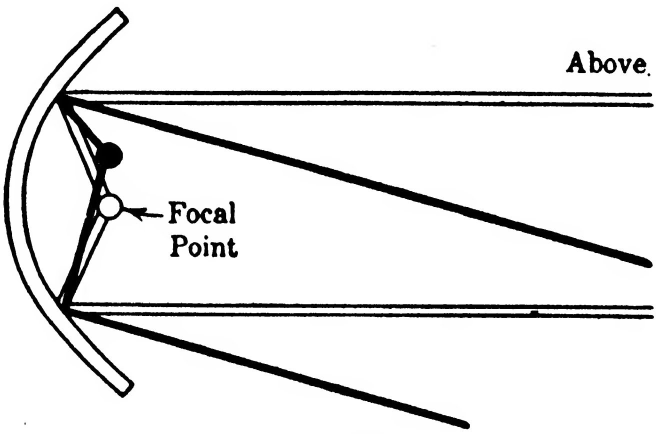


FIG. 207.

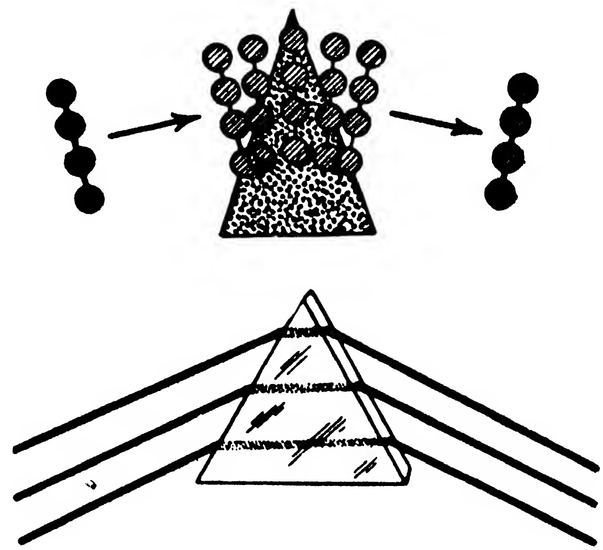


FIG. 208. Just as the men who are marching in the sand will be slowed down, with a consequent change in the direction of line of march, so light rays are bent as they pass through the prism.

physicist, *Jean Léon Foucault*, re-established Huygens' wave theory by showing that light travels through water with a velocity about three quarters of that of light through air.

When light passes from one medium to another, it is bent (refracted) because of the fact that it travels with a different velocity in the second medium. Thus a pencil placed in a glass of water appears to be bent at the surface of the water.

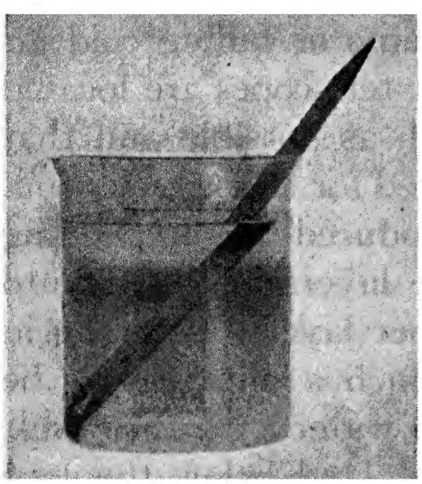


FIG. 209. A pencil appears bent at the point where it dips into the water.

If a coin is placed at the bottom of an evaporating dish slightly below the line of vision, it will be invisible to the audience until water is poured into the dish. See Fig. 210. Water appears to be shallower than it really is because of refraction.

We actually see the sun about 8½ minutes after it has gone below the horizon because the light from the sun is bent toward the earth by the atmosphere.

Plate glass does not lend to objects the distorted appearance frequently seen with common window glass because it is of uniform thickness and density, whereas the variations in the thickness and density

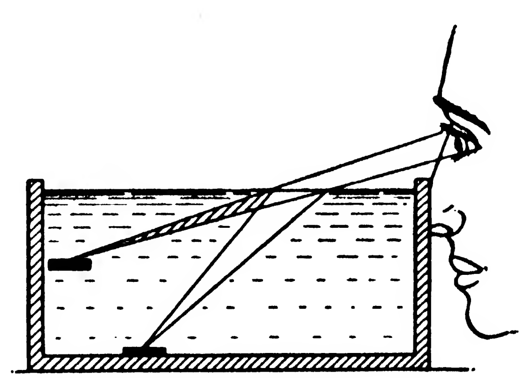


FIG. 210.

of window glass result in the light being refracted more at one point than at another. Light passing through homogeneous media having parallel surfaces does not change direction.

The angle of refraction in a medium depends upon the angle of incidence, and if the angle of incidence is great enough there will be no

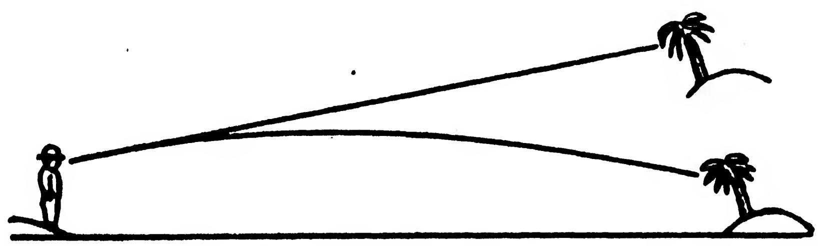


FIG. 211. In this type of mirage two images are seen, an apparent one and an actual one. The apparent image is due to the refraction of the light as it enters an upper warmer layer of atmosphere.

refraction. This angle, which is the essential condition for total reflection, is known as the *critical angle*.

On a hot day objects on the horizon seem to quiver and are not distinct because the velocity of light in air varies with the temperature; the light is therefore refracted as it passes through layers of air of different temperatures and hence also of different densities. Convection currents of rising hot air become apparent because of the refraction of the light as it passes from cooler to hotter portions of the air.

The twinkling of the stars is the result of the refraction of the starlight as it passes through rising hot air currents or falling cold air currents. It has already been pointed out that telescopes are located on mountain tops to avoid this effect as much as possible and that the rooms containing telescopes cannot be heated for the same reason.

A type of mirage due to refraction is that produced by the bending of light rays as they pass from chilled surface layers of the air into warmer upper layers, as shown in Fig. 211. Such a mirage may be formed over water with the result that ships or land below the true horizon become visible.

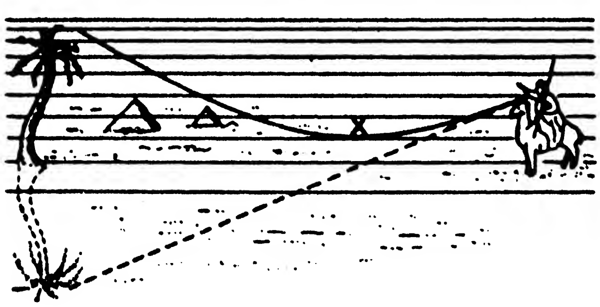


FIG. 212. A mirage. (From *Optics and Wheels*, Courtesy of the General Motors Corporation.)

Another type of mirage, illustrated in Fig. 212, is the desert mirage. In this case light from a distant object is bent as it passes from the cooler upper layers of air to the hot surface layers of air until it reaches the critical angle X, at which point the image is reflected as from a mirror. This same effect

is responsible for what appear to be puddles or sheets of water ahead of an automobile on a hot road.

The densities of different liquids and solutions can be measured by use of refractometers, which measure the refraction of light in the different media. Such instruments are of great value in the analysis of liquids and solutions.

The Lens Is One of the Most Widely Used Optical Devices.

The lens is the essential part of telescopes, microscopes, cameras, projectors, and spectacles. All lenses are merely devices to bend light rays in the desired direction.

Figure 213 shows how convex and concave lenses bend light rays.

Two of the most remarkable applications of lenses are the cystoscope and the gastroscope, which consist of long thin tubes, containing lenses, with a small electric light at one end. This tube is inserted into the bladder or the stomach, as the case may be, to illuminate the interior of the organ. The system of lenses in the tube makes it possible to obtain photographs of the interior of these organs.

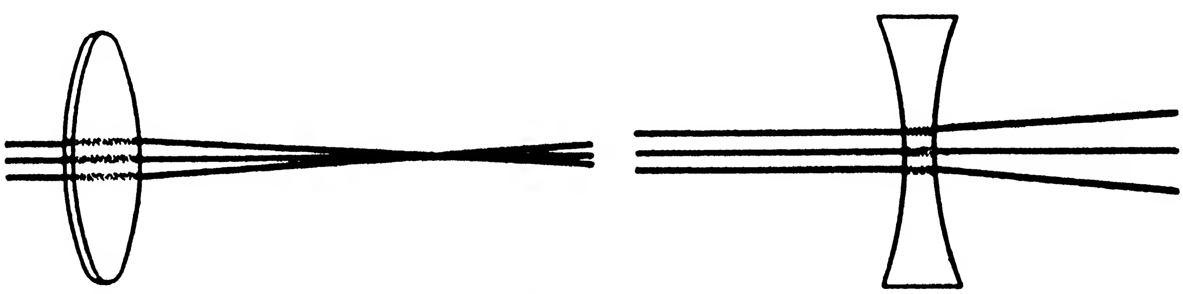


FIG. 213.

The Eye Employs an Adjustable Lens.

The eye is similar in principle to the camera, except that it focuses objects by varying the curvature of the lens rather than by varying the distance of the lens from the receiving medium.

Nearly 25,000,000 Americans wear glasses, and 60,000,000 should. The majority of errors are errors of refraction, *i.e.*, light rays are not properly focused on the retina.

The diagram shows the essential features of the eye, namely: a dark chamber, a lens, and a surface sensitive to light called the *retina*. The lens of the eye is a double convex type, whose curvature is changed by muscles attached to it so that the eye can focus on near or distant objects.

The iris of the eye corresponds to the diaphragm of the camera, similarly dilating or contracting to control the amounts of light passing through the lens.

Near-sightedness and far-sightedness are the results of elongated and shortened eyeballs respectively. People who have these defects either cannot bring near or distant objects into focus, or they subject their eyes to undue strain in so doing. Such defects are corrected by the use of concave or convex lenses.

Another common eye trouble is astigmatism. Astigmatism will cause more discomfort and eyestrain than any other type of eye defect. The eyeballs in this case are slightly cylindrical in shape, so that two

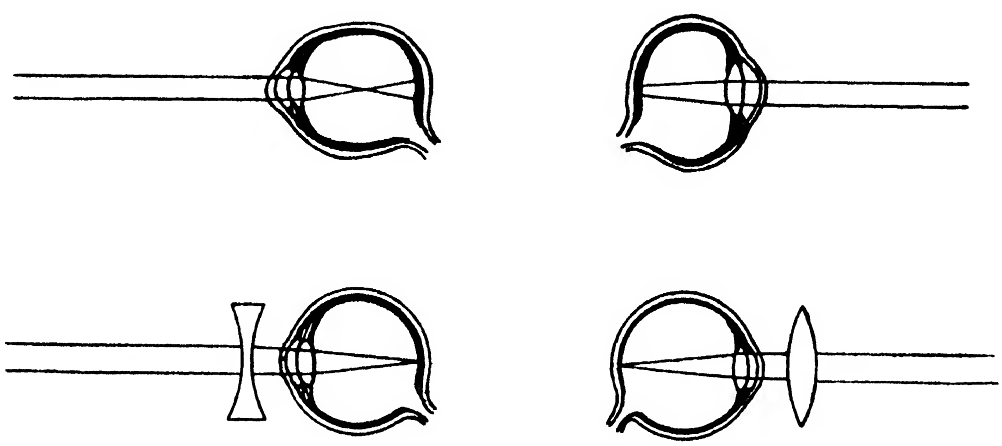


FIG. 214. The different types of eye defects and the types of lenses required to correct these defects.

equally distant lines at right angles to each other will not be in the same focus. Astigmatism is corrected by use of a cylindrical lens. Double vision or unequal focus, which at its worst is represented by crossed eyes, is due to muscle unbalance. Extreme cases may be overcome by delicate operations on the muscles, and less severe cases can be corrected by means of prismatic lenses.

Aniseikonia, Greek for "unequal images," is a condition in which the images received by the two eyes differ in size and shape. People afflicted with this defect lack depth perception and distance sense and should not operate automobiles or airplanes. The eye strain resulting from this disorder frequently causes headaches and stomach or nervous disorders. Aniseikonia can be corrected by "tailor-made" lenses.

STUDY QUESTIONS

1. Mention three types of eye defects. What is the cause in each case? How is each type corrected?
2. What is the principle involved in red reflectors?
3. What is meant by *reflection* and *refraction* of light?
4. Why does the sky appear light on the earth's surface in the day, while it is very dark at higher altitudes?
5. Why does a pencil placed in a glass of water appear to be bent at the surface of the water?

6. What causes the stars to twinkle?
7. Explain the desert mirage.
8. Explain the hot-pavement mirage.
9. Why is it that one can see the sun rise in the morning before it has really risen above the horizon?
10. What are the advantages of sealed-beam headlights?
11. Explain how traffic and driving lights are obtained in modern two-filament headlights.
12. Explain how glass can be rendered invisible.
13. Point out some of the applications of rendering glass invisible by the use of thin films.
14. Why is one likely to be deceived as to the depth of a pool of clear water?
15. How can one judge how far ahead a car is at night?
16. Define the terms: transparent, translucent, and opaque.
17. Differentiate between refraction and diffraction.
18. Differentiate between scattering and diffraction.
19. What evidence can you give to prove that light travels in a straight line?

UNIT VI

SECTION 6

ILLUMINATION IS THE CHIEF APPLICATION OF ARTIFICIAL LIGHT

Introduction.

Illumination deals with the problems of what kind of light sources to use for a given purpose, how much light is required, how the amount of light present can be measured, and where light sources should be placed.

Tremendous strides have been made in the science of illumination, and yet few homes are properly illuminated. Proper illumination is desirable because it saves eyestrain. In this age, when the eyes are used so much in reading and close work, it is very important that everything possible be done to relieve the eyes from unnecessary strain.

Illuminating Power Is Now Measured in Terms of Lumens.

The value of any light source for illumination depends upon how much light it gives out. The unit of intensity is called the *candle*, which is equal to the intensity of a standard candle burning under

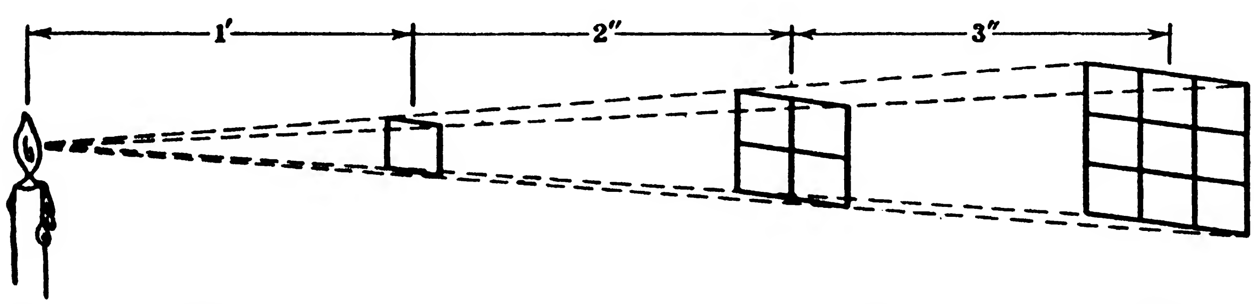


FIG. 215. Light intensity is inversely proportional to the square of the distance from the source.

specified conditions. The *international candle* is now defined to be the light with an illuminating power equal to one tenth of that of a standard gas light produced by a Harcourt pentane lamp. Obviously the intensity of the light from a burning candle depends upon the distance one is from it, so that one must incorporate the idea of distance into the measurement of illuminating power. A *foot-candle* is the most con-

venient unit of intensity; it represents the intensity of a candle light at a distance of one foot from the candle.

The lumen is now replacing candle power in measuring illumination. The lumen is really a light energy unit; it measures the quantity as well as the intensity of light because it combines the idea of area with intensity. The lumen is the amount of light falling upon a surface which has an area of one square foot when every point of the area is one foot from the light of one standard candle. The lumen corresponds to the ampere used in measuring the rate of flow of electricity, in that it measures the rate of flow of light energy. Light intensities are expressed in lumens per square foot or in foot-candles.

The Measurement of Illumination Is a Common Occurrence, Especially in Photography.

The strength of a light source is measured by a photometer. In the simple photometer used by Rumford, the distance of two light sources from a rod is varied until the shadows are of equal intensity. The relative strengths of the two light sources can then be computed on the basis of their relative distances from the rod.

The intensity of light is now measured for photographic purposes by means of light-meters, which the photographer calls *exposure meters*. These are simply photoelectric cells in circuit with sensitive galvanometers which measure the electric current from the photoelectric cell when light shines upon it. Photoelectric cells will be discussed in a later section.

The intensity of light may also be measured by actinometers, which measure the amount of a substance produced in a chemical reaction in a given time as a result of exposure of the reactants to light.

The Amount of Light Required Depends upon the Person and What He Is Doing.

Different persons require different amounts of light, depending upon their sensitiveness to light. Certain conditions of eyestrain will cause such a sensitivity to light that people so afflicted can scarcely stay in the room that is adequately illuminated for other people. As a rule, older people require more light than young people.

The amount of light required for good illumination also depends upon the nature of the operation involved.

The following values represent good lighting practice:

3 foot-candles — stairways, passageways, etc.
3–10 foot-candles — power plants, elevators, etc.
5–10 foot-candles — general household-work.

10–15	foot-candles	stores and general factory work.
10–20	foot-candles	offices and classrooms, general reading, writing, and sewing.
20–30	foot-candles	typing and average office-work.
20–50	foot-candles	drafting and fine office-work, prolonged reading, especially of fine print, fine needle-work.
50–100	foot-candles	fine manufacture and inspection.

Your local power and light company will undoubtedly be glad to render you the service of measuring the intensity of illumination at various points in your home, office, or shop. This service may be combined with an attempt to sell you lighting equipment, and it is quite probable that the service man can give you expert advice concerning the types of equipment available.

In general, however, once the diagnosis has been made, one should not take the first cure offered. There may be other equally effective, more pleasant, and even less expensive, cures available.

In building a new home, the architect is sometimes competent to work out the illumination problems, but it is often desirable to obtain the help of an illumination engineer. Illumination is a technical matter that requires the aid of a specialist just as sickness requires the aid of a physician.

Glare and Shadows Should Be Avoided in Illumination.

In designing a lighting system, whether for home, office, or factory, one should try to avoid glare and shadows which cause eyestrain. In general, one should keep in mind that it is not the light source that one wants to see but rather the book, merchandise, or machine, as the case may be. Floor lamps and table lamps are good as decorations, but they are poor for general illumination because they represent light sources which are in the direct line of vision. Flush-type ceiling lights, cove-lighting, concealed floodlighting, and similar types of lighting represent good lighting practice because the *luminaires* (luminaire refers to a light unit which includes lamp fixture, shade or globe) are kept out of sight, while the light is directed everywhere.

Shadows and all sharp contrasts in illumination should be avoided because it takes some time for the eye to become adjusted to any given light intensity. A camera which has been adjusted to take a picture in the bright sunlight has to have its diaphragm opened to allow more light to get in for exposure on a cloudy day. When one shifts his eye from a brightly illuminated book to an object in a poorly illuminated dark corner, it strains his eyes to see anything. Everyone knows that it takes time to adjust one's eyes to see outdoors at night when one

12. Why are table lamps and floor lamps used more widely than flush-type lights, cove-lighting, and lens-lighting?
13. If one 100-watt light bulb provides adequate light intensity for reading in a floor lamp placed so that the light bulb is three feet from a book, how many 100-watt light bulbs would be required in a flush-type ceiling fixture, eight feet from the book, provided that the same types of reflectors were used in each case and no diffusing globes or plates were placed on the lamps?
14. Why should one select different types of glass blocks for different exposures?
15. Why are electric-light bulbs frosted?
16. What changes would inexpensive fluorescent lamps or zeon lights probably make possible in the illumination of houses?
17. Why is indirect lighting more costly than direct lighting?
18. Compare direct, indirect, and semi-indirect lighting with outdoor natural lighting.
19. Would you prefer to read out-of-doors in direct sunlight or diffused sunlight? Why?
20. Why is the glare out-of-doors worse on a cloudy day than on a clear day? What application of this fact can you make to indoor illumination?
21. Why is the light transmitted through a window with a north exposure preferred for drawing and artwork? What type of artificial illumination most closely resembles the light from a north window?

UNIT VI

SECTION 7

SOUND IS PRODUCED BY VIBRATIONS IN MATTER

Introduction.

The sense of hearing is next in importance to the sense of sight in enabling us to receive impressions from a distance. In this Section we shall consider the nature and characteristics of sound waves, which are produced by vibrations in matter.

Sound Waves Are Longitudinal or Compressional Waves.

Light waves are transverse to the direction in which the wave travels, whereas sound waves are longitudinal, *i.e.*, they lie along the direction in which the wave travels.

Sound waves are compressional waves. The elasticity of the original layer of air compressed by the sound source makes it expand, thus passing on the state of compression to the next layer of air beyond.

Sounds Are Transmitted by Waves in Matter.

Any stimulus which will produce the sensation of hearing is called a sound. This sensation is produced by vibration of the eardrum, which, in turn, is caused to vibrate by a wave motion of some medium, usually the air. The compressional waves in this medium itself are produced by the vibration of some body. The air is not essential for the transmission of vibrations to the ear. Any medium which can transmit compressional waves will serve. A swimmer can hear better under water than above water, because water carries vibrations faster and with greater intensity than air. If the ear is placed on a railroad track, the sound of an approaching train can be heard, because solids like wood or steel transmit vibrations.

Vibratory motion is the commonest of all motions. Automobiles, bridges, and buildings may be caused to vibrate all too easily. Nearly any material is more or less elastic and will resist any attempt to deform it, thus producing vibrations when the deforming force is released. Sounds may be produced by blows, as with a hammer, by explosions, by compression, or by any other type of deformation, such as a pull or a twist.

The singing of teakettles shortly before the boiling-point is reached is due to the fact that the condensation and collapse of steam globules as they rise into the colder water near the surface set up vibrations within the liquid. This process is called *cavitation*.

Sound waves differ from electromagnetic waves in that the former are transmitted by matter, while the latter are transmitted through empty space. The fact that sound waves require matter for their transmission can be readily demonstrated by ringing a bell in a jar which can be evacuated. As the air is removed, the intensity of the sound decreases until it can no longer be heard. It is important to remember that waves are disturbances that travel in a medium but that the material of the medium itself does not travel.

Sound Waves Travel Much More Slowly than Light Waves.

The thunderclap is heard some time after a distant flash of lightning is seen. The jet of steam from a distant steamer is seen before the sound of the whistle is heard. Other common observations lead to the conclusion that an appreciable time is required for sound to travel from one point to another.

The velocity of sound in dry air is 1085 feet per second at 0° C. and increases at the rate of 2 feet per second per degree C. rise in temperature. Corrections for both the temperature and moisture content of air must be made in calculating the speed of sound in air, because the velocity imparted to molecules depends upon their masses rather than their number. Slight changes in barometric pressure do not affect the speed of sound because they merely determine the number of molecules present. Temperature affects the speed of sound in air because it changes the natural speed of the molecules. It thus becomes evident that the presence of water vapor changes the density of the atmosphere by introducing molecules of different mass, while changes in the density of the atmosphere due to barometric changes are the result of changing the number of molecules present in a given volume. The velocity of sound in water is more than four times as great as that in air, and in steel it is nearly fifteen times as great as that in air.

Sound waves, like light waves, may be reflected. Echoes are reflected sound waves. Thus the distance between two objects may be determined by noting the time required for a given sound to return to its source as an echo. The combined effect of wind, humidity, and temperature on the passage of sound through air often causes sound-locating instruments to make serious errors; for example, three trained anti-aircraft units in England on May 23, 1917, reported that airships were nearly overhead, though in reality they were 25 miles distant.

There Are Many Interesting Consequences of the Relatively Small Velocity of Sound in Air.

Many curious effects can be explained by the relatively small velocity of sound in air. An observer can see that the marchers in a parade some distance behind the band lag in their step because they are marching with the music. It seems to a listener at some distance and to one side of a large chorus or orchestra that the most distant musicians lag behind those who are closer, although they are all kept together by the conductor.

All Sound Waves in a Given Medium Travel at the Same Speed.

It will be recalled that a prism refracts light into a colored spectrum band because the longer waves travel with a greater speed than the short waves through any material. In the case of sound, the velocity in a given medium is not affected by the wave length, except for very intense sounds. If this were otherwise, the music from an orchestra, for example, would be considerably distorted.

Compressional Waves May Be Produced by Vibrating Bodies.

Pitch (*i.e.*, the sensation of highness or lowness) depends upon the number of times a body vibrates per second (*i.e.*, the frequency), and the frequency of the vibrations determines the number of compressional waves set up in the atmosphere. Pitch is subjective, while frequency is the objective physical magnitude. Inasmuch as sound always travels at the same rate through the atmosphere under the same conditions, it follows that the more waves there are per second the shorter will be the *wave length* (*i.e.*, the distance from rarefaction to rarefaction, or from compression to compression).

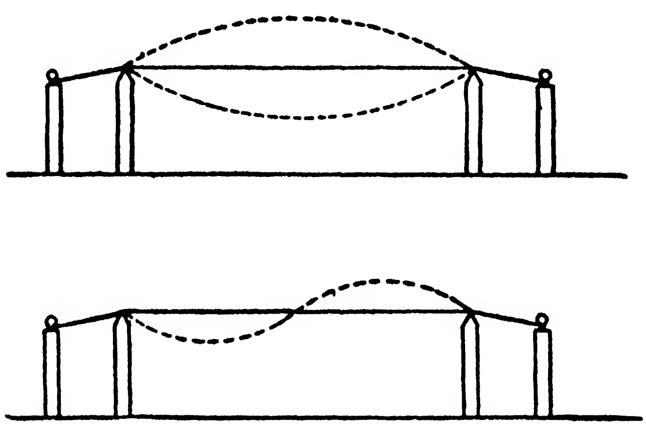


FIG. 216. The pitch is determined by the number of vibrations per second.

The amplitude of the vibrations of a body determines the energy carried by compressional waves. The total amount of energy carried by compressional waves per second will be a product of the frequency by the energy carried by each wave. The total amount of energy per second therefore depends upon both the square of the frequency and amplitude of the generator.

The intensity of compressional waves, like the intensity of any kind

of energy or force spreading out from a central point, is inversely proportional to the square of the distance from a source, because the area of a sphere carrying a given amount of energy increases as the square of the radius. Thus if the distance from the source, *i.e.*, the radius, is tripled, the area of the sphere will be increased nine times, and the amount of energy in the same area of the wave would be only one-ninth as much as at the start, because the original energy has been distributed over nine times as much area.

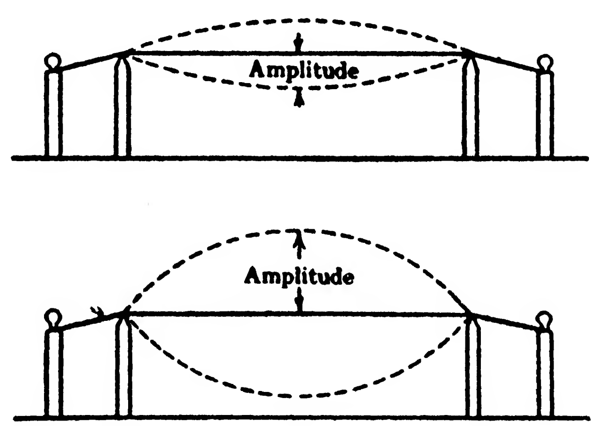


FIG. 217. Intensity depends upon amplitude

The sensation which we call the *loudness* of a sound depends upon the intensity of the compressional waves, and it therefore also depends upon the amplitude of the vibrations in the generator which caused the compressional waves.

If all the energy of a voice of a lecturer in an average auditorium were absorbed and changed into heat, it would be necessary for the lecturer to talk for a hundred years without interruption in order to raise the temperature of a one-centimeter layer of water on the walls and ceiling one degree centigrade, assuming that there was no gain or loss of heat during that time.

Speaking-tubes, Ear Trumpets, and Megaphones Are Designed to Increase the Intensity of Sound.

When sound waves spread out in every direction from a source of sound, the energy is spread over increasingly large wave fronts, and as a result the intensity of a sound varies inversely as the square of the distance from the source.

Speaking-tubes and the tubes of a stethoscope prevent the sound waves from spreading out and thus transmit the sound with little decrease in intensity. Long corridors are similar to speaking-tubes in their transmission of sound with little loss of intensity.

One type of airplane-detector is really a very large stethoscope, consisting of two large conical trumpets, mounted so that they can be rotated about a vertical axis and having their small ends leading to the ears through rubber tubes. The sense of direction is made possible by the use of one trumpet for each ear.

Ear trumpets concentrate the energy of large areas of incoming sound waves into a small area and thus increase the intensity.

The walls of a megaphone prevent the sound waves from spreading out as soon as they would spread from the mouth.

Sound Waves May Be Refracted.

Inasmuch as sound travels at different speeds in layers of air of different temperature and relative humidity, sound waves may be bent as they pass from one medium to another, as shown in Fig. 218, to the extent that the convex waves become concave in nature and thus focus the sound at a given point. The sound thus appears to travel farther under these conditions. The sound of a guitar played on a boat on a lake on a hot summer night will travel long distances with remarkable clearness because of the refraction of the sound waves by the warm air over the cooler water.

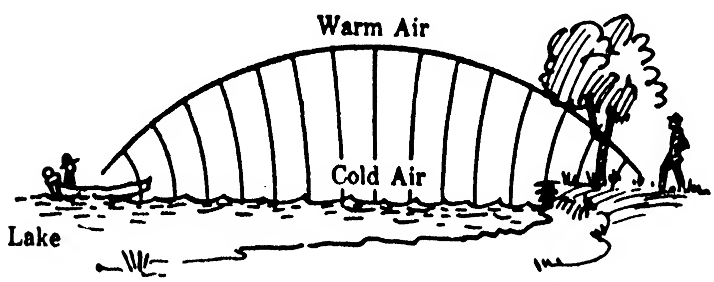


FIG. 218. Sound waves are refracted as they pass from cold air through warm air.

Sound Waves May Be Analyzed by Methods Which Use Compressional Waves to Produce Corresponding Wavelike Patterns in Beams of Light.

Curves showing the nature of sound waves can be obtained by an instrument called the "phonodeik." The principle here employed is that the vibrations in the air move a sensitive diaphragm, which is attached to a mirror reflecting a beam of light to a motor-driven revolving mirror, which, in turn, throws the beam of light on a screen in the form of a long wave. It is important to keep in mind that the waves in a beam of light do not resemble compressional waves in the atmosphere but rather serve as a diagrammatic representation of sound waves.

Sound waves may also be directly recorded by the phonautograph, in which a stylus attached to the diaphragm traces a path on a smoked paper carried on a rotating cylinder.

The telephone diaphragm and the microphone generate oscillating currents from sound waves, which may be received by a cathode-ray type of oscillograph. This oscillograph is of great value in telephone and radio research and testing.

The phonograph, invented by *Thomas A. Edison* in 1877, recorded the movements of a stylus controlled by a diaphragm, by indentation in a sheet of tinfoil supported over a spiral groove on a metal cylinder. Later machines made the records on wax cylinders or disks. Such

records can be greatly amplified by a special apparatus designed for the purpose of giving curves similar to those produced by the phonodeik. The phonograph not only records sound but also reproduces the sound thus recorded, because the diaphragm is caused to vibrate as the needle runs over the sound track. Thomas Edison's phonograph was followed by a series of improved machines under such trade names as the "graphophone," the "gramophone," the "electrola," and the "victrola." Today a very useful application of the phonograph is the dictaphone.

Phonograph records are first made in wax, dusted with graphite, and electroplated to make the master disks. These master disks are used to make faithful impressions on plastic materials of various compositions in the hydraulic press. The loudness of a sound produced by a record depends on the depth of the track, while the pitch depends upon the relative frequency of the elevations and depressions of the vertical cut record. If the records are played too slowly the pitch is cut down. In the case of lateral-cut records, the loudness depends upon the swings of the track away from the center line.

Modern instruments use electrical transcription which employs the vacuum tube (as described in Unit VII). Some sound motion pictures use a sound track produced on film by a device in which sound energy is transformed so as to vary the intensity of light falling on the film. Light passing through this sound track produces variations in the light received by the photoelectric cell, which changes the light into electrical impulses. These variations in electrical current are then amplified, as in the radio, by vacuum tubes, to a point where they can operate electromagnets powerful enough to cause rather large diaphragms to vibrate and produce the usual sound of the loud-speaker.

Overtones Are Vibrations of Greater Frequency than the Fundamental Vibration.

The time required for one complete vibration is called a *period*, while the number of complete vibrations (cycles) per second is called the *frequency* of a vibrating system.

A string is capable of vibrating as a whole, thus producing the fundamental tone, or it may also vibrate in segments, giving not only the fundamental vibration but a series of higher tones. These higher tones, produced by vibrations of greater frequency, are called overtones. When the set of vibrations has frequencies in the ratios of the natural numbers, 1 : 2; 3 : 4; etc., it is called a harmonic series. The overtones of many vibrating bodies are not harmonic. For example, the overtones in the xylophone are in the ratios 1 : 2.756 : 5.404, etc.

A tone rich in overtones is carried to the ear by a mixture of compressional waves of different frequencies and different intensities, all traveling in the same direction.

There Is a Vast Range of Frequencies for Sound Waves.

Pitch can be expressed in terms of frequency by comparison with sounds created by mechanical means that produce a known number of vibrations per second.

If a card is held against the serrated edge of a revolving disk, it will produce vibrations whose frequency depends upon the rate at which the disk moves.

Of course, pitch can be obtained from records produced by the phonautograph, the phonodeik, and similar instruments, but it can also be determined by means of tuning forks which vibrate with known frequencies. Two sound waves whose frequencies are 250 and 251 per second will be in phase [1] at one instant and produce the maximum sound, but half a second later they will be opposite in phase, and less sound will be heard because of interference. At the end of the second they will be in phase again, and the sound will again be heard. If the frequencies had been 250 and 252, there would have been two of these variations of loudness, otherwise known as "beats." In comparing the pitch of a vibration whose pitch is not known with a known pitch, the difference in the frequency between the tones is equal to the number of beats heard per second. This method of tuning instruments is sufficiently accurate for most purposes. The charm of music produced by bells is due in part to the beats that accompany their tones.

Middle C on the piano has a frequency of 258.7 complete vibrations (cycles) per second on the International Scale. An octave consists of the range of pitch between any two frequencies in which one is twice the other. The piano has a range from 27.2 to 4138.4 complete vibrations per second. The range for the organ is 16 to 4138 complete vibrations per second. The organ pipe giving 16 complete vibrations per second is about 32 feet long. A few organs have pipes 64 feet long that give only 8 complete vibrations per second. The organ pipe that has a frequency of 4138 complete vibrations per second is only 1½ inches long.

There are upper and lower limits to the pitch of notes which can be heard by the ear, but both limits vary with different persons. Few

[1] *Phase* — Imagine two boys swinging in two identical swings placed side by side, the period in each case being the same. If the two boys reach the same relative positions at the same time, they are in phase. If they are opposite each other when they reach their greatest height, there is a phase difference of 180°, while, if one boy is at the height of his swing while the other boy is at the lowest point of his swing, there is a phase difference of 90°. Any other combination of swings which are out of phase could be worked out.

people can distinguish frequencies fewer than 12 to 16 per second or more than 20,000 per second. Frequencies above 5000 per second produce sounds that are mere squeaks or unpleasant shrill notes. Younger people can usually distinguish higher frequencies than can older people.

Soundless Sound Waves Have Many Possible Applications.

The frequencies above the upper limit of hearing are called "supersonic" vibrations; frequencies up to and beyond five million per second have been produced and measured. These higher frequencies are carried through the air at about the usual speed for sound waves, but they are absorbed by carbon dioxide. They may be transmitted through water and could be used as a means of communication between ships.

Some experiments with powerful supersonic sound waves indicate that they have possibilities in reducing the smoke nuisance by causing smoke particles to coagulate.

Sounds can bring about chemical reactions if the sounds are intense enough. Thus proteins have been coagulated, ethyl acetate has been broken down to produce acetic acid, vegetable oils have been cracked, and starch has been changed to glucose with sound waves. This is a subject that is certain to attract a great deal of research in the future.

It is possible to create burns on the fingers by holding a glass rod which is dipped into ultrasonically vibrating oil, although the temperature of the oil is at ordinary room temperature. The glass conducts the sound to the fingers because it is a better conductor than is oil.

The application of ultrasonic vibrations to an arm or leg will heat the marrow of the bone, although the bone remains at normal body temperature. Bone conducts vibrations, whereas flesh and marrow absorb them and, as a consequence, become heated.

Milk and photographic emulsions may be homogenized by ultrasonic vibrations.

Submarines may communicate with each other over distances of ten to fifteen miles, using ultrasonic beams which can be concentrated within one degree of the desired direction.

The Doppler Effect Is the Apparent Change in Frequency Produced by the Relative Motion of a Sound Source and an Observer.

If the horn of a passing automobile is blown continuously as it approaches and passes an automobile moving in the opposite direction, the pitch will decrease as the automobile passes and recedes relative to the observer, and the change in pitch will depend upon the relative

speeds of the two cars. The same effect may be observed as the whistle of an approaching locomotive decreases in pitch as it passes and recedes from an observer. This apparent change in frequency, produced by the relative motion of a sound source and an observer, is called the *Doppler effect.*

The Doppler effect results from the fact that when the distance between the sound source and the observer is decreasing, the number of waves entering the ear per second is increased, and vice versa.

The same effect produced in light rays was discussed in Unit II, Section 3.

The Ear Includes a Device to Convert Compressional Waves into Mechanical Vibrations.

The perplexing problem of how we hear has been the object of a great deal of research. How does the ear differentiate between the buzz of a mosquito, the shrill shriek of a siren, the high tones of a violin, and the

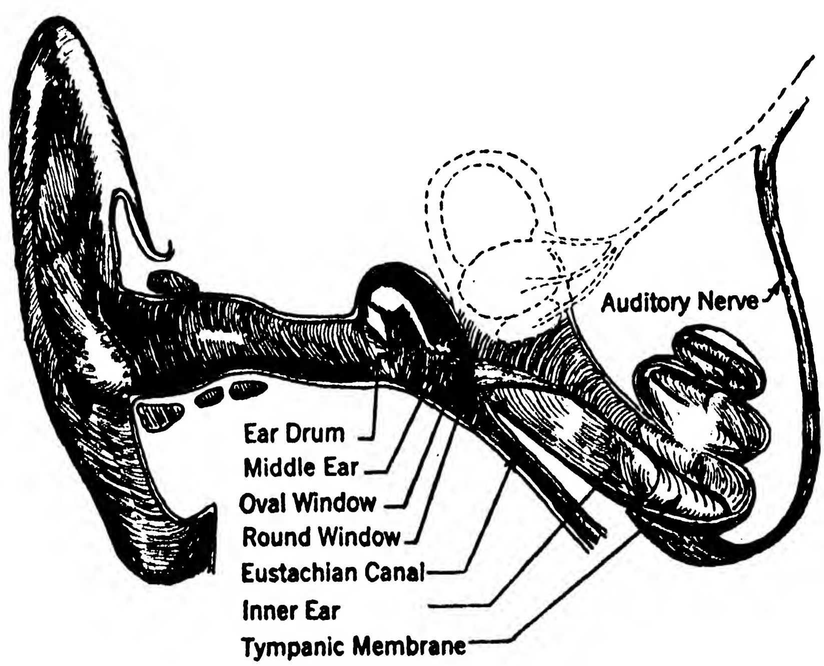


FIG. 219. Diagram of the ear.

deep rumble of the bass drum? How can all of these things be heard at once and be recognized? How can the student hear a speaker when his neighbors are carrying on a competitive conversation? What is the advantage of two ears?

One hypothesis that helps to answer some of these questions is that parts of the membrane of the ear are tuned to a certain frequency and vibrate when compressional waves of that frequency are received. A nerve fiber attached to that part of the membrane would then conduct the impulse to the brain.

A study of the ear will show the basis for this hypothesis.

Our hearing apparatus is divided into three chambers, shown in Fig. 219. The first chamber, the outer ear, consists of a short narrow tube, which, connecting with the ordinary, visible portion of the ear, acts on the principle of the speaking-tube, megaphone, or stethoscope to concentrate sound in one direction by means of reflection. The stethoscope is simply a small funnel-shaped tube which is placed in contact with the patient's body and from which sounds are conducted through small tubes to the physician's ear. This short, narrow tube of the outer ear is closed at its inner end by an elastic diaphragm, the eardrum. The middle ear consists of a system of three little bones, one end of which is attached to the eardrum and the other to another diaphragm, the oval window. The middle ear acts as a sort of lever to transmit vibrations into the inner ear. The vibrations are thus transmitted with decreased amplitude and increased force.

The inner ear is filled with liquid and contains a coiled spiral enclosure with bony walls in the shape of a snail's shell. The length of it, except at the tip, is divided by the basilar membrane, where the auditory nerve endings are to be found.

There is another flexible window between the middle ear and the inner ear. Its purpose seems to be to provide for the vibrations in the fluid of the inner ear. Something has to give way as the oval window vibrates, and the liquid in the inner ear is practically incompressible, while the walls are rigid. The vibrations are thus transmitted up one side of the basilar membrane from the oval window and down the other side to the round window. The higher-frequency vibrations appear to be transmitted directly through the lower part of the basilar membrane. Low-frequency vibrations are transmitted by the liquid around the top of the membrane, while vibrations of intermediate frequency are transmitted by both methods.

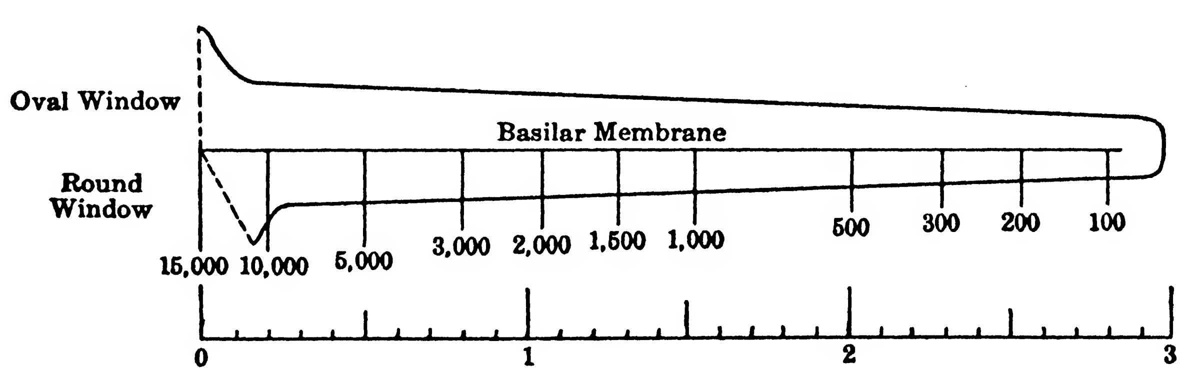


FIG. 220. The inner ear straightened out. (After Fletcher.)

Figure 220 shows the spiral of the inner ear straightened and much simplified. The frequencies to which given portions of this membrane are believed to respond are indicated.

The Ear Is Remarkably Sensitive.

The human ear can detect sharp sounds that occur at intervals as close as a twentieth of a second. It can discriminate between tones or musical notes whose frequency differs by less than 1 per cent. It can analyze and sort out the components of a mixture of sounds, concentrating on one at a time. At least a part of this action, of course, must occur in the brain. The other part of it may be due to the fact that we have two ears, which enable us to determine the direction from which a sound comes. A sound coming from the left will reach the left ear before it reaches the right ear, and vice versa.

Some deaf persons may be made to hear by vibrations which are transmitted through the bones of the skull, which cause the liquid in the inner ear to vibrate, provided that the deafness is not due to an abnormal condition of the inner ear. One can determine whether it is the inner or outer portions of the ear that are not functioning properly by use of the tuning fork. If a tuning fork is heard better when it is placed next to the skull than when placed near the ear, the outer portions of the ear are abnormal. Certain hearing-devices amplify compressional waves and change them into vibrations which are transmitted through the bones near the ear, rather than through the outer ear.

A very common type of deafness in factories, busy streets, airplanes, and even classrooms is the deafening due to masking. Under such noisy conditions one has to talk as loudly as possible in order to be heard, and it is no wonder that many students in noisy classrooms do not hear what the teacher is saying — they are "noise" deaf.

STUDY QUESTIONS

1. Define pitch, intensity, and quality of sounds.
2. How could you prove that sound does not travel in a vacuum?
3. What is the effect of temperature on the velocity of sound in air? Work out an explanation of this effect.
4. Why does sound not travel through a vacuum?
5. What is the velocity of sound in air?
6. What is a harmonic series of overtones?
7. Suppose that one sees the steam of a whistle one minute before he hears the sound; how far away is the whistle?
8. What is meant by the frequency of sound waves?
9. Compare sound waves with electromagnetic waves as to the medium in which they travel and as to their rate of motion and sources.
10. In how many different ways may sounds be produced?
11. What is sound?
12. How may sound waves be analyzed?
13. Why do deaf people often place cupped hands behind their ears?

14. What is the effect on the pitch of the sound produced by a sound motion-picture machine when the film is speeded up?
15. How fast would an airplane have to travel in order to catch up with the sound waves produced by its motor?
16. Suggest several reasons why sounds carry better on a foggy night than on a hot, clear, windy day.
17. In what respect is it correct to speak of supersonic waves as soundless sound waves?
18. Discuss some of the applications of supersonic frequencies.
19. What is meant by "noise deafness"?
20. Describe the human ear and explain why it is possible to hear and recognize several sounds simultaneously.
21. What is the Doppler effect? Illustrate with some examples.
22. What is the frequency range to which the human ear is sensitive?
23. Discuss the principle of the phonograph.
24. What is meant by the statement that a speech has been broadcast by electrical transcription? What are the advantages which electrical transcription makes possible to radio broadcasting?
25. Suggest some possible uses of electrical transcription in the school.
26. What is meant by saying that sound waves are compressional waves?
27. Mention some of the consequences of the relatively small velocity of sound in air.
28. What other information besides the time required for a sound to travel from a ship to the ocean bottom and back again would be required to determine the depth of water by depth-sounding devices?
29. In what respect would an airplane position-finder based on the reflection of electromagnetic waves be superior to one based on the reflection of sound waves?
30. Compare living in the country with living in a city from the point of view of sound.
31. What are some of the modern trends in the elimination of noise in cities?
32. Discuss social intelligence as applied to the use of a radio.
33. Discuss the factors which control the intensity of sound.
34. Differentiate between the intensity and loudness of sound.
35. Would ultrasonic sound waves be more or less intense than audible sound waves of the same amplitude? Why, or why not?

UNIT VI

SECTION 8

ACOUSTICS IS A PROBLEM OF MODERN CIVILIZED SOCIETY

Introduction.

One can scarcely hear himself talk in many factories where machinery of all kinds is creating a ceaseless din and clatter of squeaks, rumblings, rattles, and hammerings. Modern warfare is characterized by the sounds of airplane motors, machine guns, exploding bombs, and heavy gunfire. The noise of streetcars, automobile horns, truck and bus gears, automobile exhausts, traffic signals, the blare of radio loud-speakers, and the cries of newsboys are so commonplace that a city dweller may find it difficult to adjust himself to the relative quiet of the countryside. While one may become so well adjusted to noises that he cannot study without a radio playing, there is no question concerning the nervous tension that is created by the continuous stimulation of the nerves of the ear by unnecessary and disturbing sounds which are called noise. Even music may be disturbing to frayed nerves.

One might almost say that one's social maturity can be judged by the amount of unnecessary noise that he makes. It is only common sense that the more noise there is, the louder one will have to talk and the more penetrating automobile horns will have to be. Progress, as far as sound in its relation to society is concerned, is represented by campaigns, laws, and methods of reducing unnecessary sounds, rather than the development of more and louder sounds. The radio loud-speaker has given man a marvelous method of amplifying sound, but the radio loud-speaker may become a public nuisance when employed by people, young or old, who are thoughtless of the sound sensitivities of other people.

This Section deals with the control of sound, which is the problem of the science of acoustics.

The Intensity of Sound Waves May Be Increased by Resonance.

The intensity or loudness of a sounding body may be increased by use of a sounding board. This principle can be illustrated by striking a

tuning fork and then holding it against the table top. The table top is caused to vibrate and thus becomes a vibrating medium of greater intensity because it has a greater surface to agitate the air against it. Inasmuch as the energy of vibration is greater, it must last for a shorter time, the vibrations dying out much faster than when the tuning fork is held in the hand. The original vibrating body is called the generator, while the sounding board is called the resonator. Thus the strings in a piano make up the generator, while the sounding board is the resonator.

There are two distinct kinds of resonators. One kind has no vibration frequency of its own and responds to all of the vibrations of the generator. Such vibrations are called forced vibrations. A second type of resonator possesses a natural frequency and strengthens sounds of its own pitch only. Such vibrations are called sympathetic vibrations or resonance. A tuning fork is usually mounted in a hollow box whose size is such that the air column will vibrate in resonance with the fork.

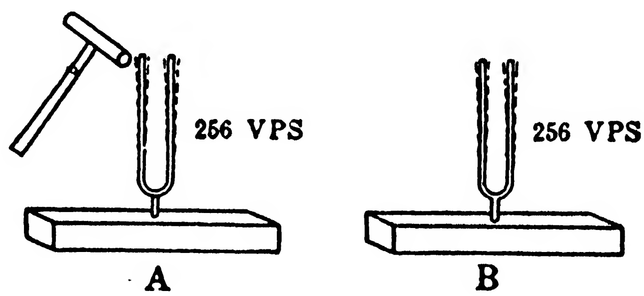


FIG. 221. Sympathetic vibrations.

Just as a child in a swing can be made to swing farther by applying a gentle impulse at the proper time, so one tuning fork can be caused to vibrate by the vibrations of another fork in tune with it. If the loud pedal of a piano is held down so that all of the strings are free to vibrate, that string will vibrate whose natural frequency corresponds to the frequency of a briefly sung note.

Sound Waves May Be Canceled by Interference.

Mufflers used to absorb or minimize sound energy from internal-combustion engine exhausts depend on the cancellation of sound waves by interference.[1] In one type of muffler the length of the closed tube is one fourth of the wave length to be canceled. Waves entering the tube are reflected and return to the main tube 90 degrees out of phase, thus canceling the incoming sound wave. In a second type of muffler one path is longer than the other by one half of the wave length to be canceled, and the waves uniting at the outlet cancel each other. Such muf-

[1] Interference may be explained by referring to a boy in a swing. If a person gives the swing a push each time it reaches the end of a swing, the swing will swing farther and farther with each push; but if a person gives the swing a push when it is not at the end of the swing, the amplitude of the swing will be decreased. A push equal to the force of the swing, but in the opposite direction, when applied as the swing comes to the position closest to the ground, will stop the motion entirely. Sound waves are canceled in the same way by other sound waves which are out of phase with the incoming sound waves.

flers do not build up back pressures and should be of value in silencing airplane exhausts.

Reverberations Are Produced by the Reflection of Sound Waves.

In the open country one can often hear several echoes produced by a loud sound as it is reflected back and forth between mountains or hills; a dynamite blast in the mountains often produces such reverberations. Reverberations are not desired in broadcasting studios and auditoriums.

Depth-sounding devices used by many ships depend upon the measurement of the time required for sound waves to travel to the ocean bottom and back to a receiving microphone. Airplanes use similar devices to determine their distance from the ground.

Sound reflection is also used in geophysical prospecting. Vibrations produced by explosions in the ground are recorded by seismometers placed at various positions. Sound waves travel faster through salt domes and other possible oil-bearing formations than they travel through solid rock.

The presence of approaching airplanes can be detected by the use of large concave mirrors, five feet or more in diameter, which converge the sound waves on a sensitive sound-detector.

The Reflection of Sound Waves Causes Acoustical Problems.

Megaphones, trumpets, and horns of various kinds act as reflectors, increasing the intensity of the sound in one direction, just as the reflector in a flashlight concentrates the light in one place.

Sounds are more intense in a room or hall, because they are reflected back by the walls. Sometimes, however, the sound has to travel so far that the reflected waves are not received at the same time that the original waves arrive. These echoes are one of the sources of poor acoustics in rooms. This difficulty can be remedied in part by hanging draperies against the walls or by lining the walls with materials which absorb rather than reflect sound. People's clothes absorb sound; the echoes characteristic of a large empty hall are not so noticeable when it is filled with people.

The scientific basis for acoustics in rooms and halls has been worked out. In order to obtain proper acoustical properties, the size, shape, and the materials of construction must be considered. After a hall is once built, consideration of the furnishings and the location of the audience and the sound source are important. It is needless to say that only highly trained specialists can be depended upon to solve these problems satisfactorily. Many large auditoriums that have been

designed without consideration of the principles of acoustics have proved to be very unsatisfactory.

Intensity of Sound Is a Major Problem of Acoustics.

In the open the intensity of sound falls off so rapidly that only speakers with very powerful voices can be heard by a crowd of people. The modern public-address system which amplifies speech by use of a radio amplification system discussed in Unit VII, Section 7, has revolutionized public speaking both in the open and indoors. It is important that the speaking units of public-address systems be properly designed and located.

Good reflecting surfaces augment the intensity of sound.

The Shape and Size of a Room Help to Determine Its Acoustics.

The old method was to design a building to fit some period of architecture and then apply corrective acoustical tricks if needed. Modern architects who plan buildings with acoustics in mind find that acoustical requirements often produce new, interesting, and pleasing shapes and contours. Acoustics should play an important part in modern functional architecture.

Large concave reflectors may be so placed in auditoriums that sound waves are reflected to the audience. The difficulty with such reflectors is that they cannot reflect the sound waves equally to all of the audience. In large auditoriums, sound waves are best reflected from large flat surfaces placed above, below, and behind both sides of the speaker. Curved surfaces are avoided because they would concentrate the sound too much in certain spots. Ceiling domes, curved ceilings, and large reflective areas at the back of a room should be avoided.

Extraneous Noise Should Be Eliminated in Offices and Public Meeting Places.

An auditorium should be located in a quiet place if possible, and it should be constructed of sound-proof, or sound-deadening, materials. Outside noises which may enter the building through small cracks around windows and doors may be kept out by means of weather stripping. The elimination of windows altogether will simplify the problem. Double sets of doors such as one finds in motion picture theatres helps to keep outside noises from coming in the doorway. Ventilating ducts should have sound-absorbing materials placed in them, or they should be constructed of sound-deadening materials so that they will not transmit the sound of the blowers or carry sounds from one room to another. Upholstered seats and carpeted floors help to prevent unnecessary noise.

One Can Learn an Important Lesson in Acoustics from the Bathroom.

It is a well-known fact that people like to sing or whistle in a bathroom. Nearly everyone sounds like an artist (to himself) in a bathroom because the reverberations in the bathroom enable the singer to hear his own voice as it is reflected back to him with little loss of energy.

The result of being unable to hear one's self sing results in tension and nervousness that decrease vocal efficiency. In the attempt to fill a hall with one's voice, one is apt to force it into too high a pitch. A modern device to aid artists utilizes public-address units directed toward the artist so that he can hear himself sing.

A room which is well adapted to speech will be too dead for music, because the musician needs reverberation in order to blend one tone into another. Music halls should be so constructed that the wall back of the music source will act as a sounding board, while the wall behind the audience should absorb sounds. Large areas of wood nailed on furring strips of variable spacing permits them to vibrate in response to quite a range of low-frequency vibrations, thus amplifying the low frequencies. These wooden surfaces should be given a highly polished finish so as to reflect the high-frequency tones, which otherwise may be readily lost by absorption.

Acoustics Should Be an Important Consideration in Building a Modern Dwelling.

In building a modern home, many acoustical problems are presented. Noises from bathrooms, kitchens, and laundries should not be transmitted to other rooms in the house. The blare of a radio in one room should not be allowed to bother the occupant of another room. There should be a room where it is possible to play various musical instruments without bothering other occupants of the house or annoying the neighbors.

Special types of acoustical boards may be used on the ceilings of kitchens or laundries to deaden sounds. Ordinary lath and plaster partitions often act as diaphragms or resonators to transmit sounds. Walls may be made sound-proof by building two or three thin partitions which are separated by absorbing materials such as cellulose building-boards. Walls constructed of hollow concrete blocks made from porous aggregates insulate against sound as well as heat. In general, the same types of material that are used for heat insulation also serve for sound-deadening.

Porous material like hair felt, cellulose fibers, and textile materials reflect only a small amount of sound and absorb relatively large amounts. Solid plaster reflects over 97 per cent of sound waves.

These differences are caused by the marked differences between the elasticity and density of air and solid materials.

STUDY QUESTIONS

1. Discuss the factors which should be considered in providing proper acoustics for an auditorium.
2. Discuss the factors which should be taken into account in the design of a modern dwelling, and explain how each factor is controlled.
3. Would it be a good idea to put sound-deadening material on the ceiling of a music studio?
4. What is the advantage of putting sound-absorbing materials on the ceiling and walls of offices, banks, and restaurants.
5. Why are the acoustics better in a crowded auditorium than in an empty auditorium?
6. Why do sounds travel better in an empty house than in a furnished house?
7. Why should we support antinoise campaigns?
8. Why do younger people like "noise" parades which may annoy older people?
9. Why should a person be quiet in schoolrooms, public libraries, churches, theatres, and other public meeting places?
10. How should a radio broadcasting room be constructed from the point of view of acoustics?
11. Why are booths provided for telephones in public places?
12. Discuss the acoustics of the library in your school. Was the library designed so as to aid in the elimination of noise?
13. Discuss the acoustics of your classroom. What would you suggest to improve it as far as acoustics is concerned?
14. Discuss the design of the auditorium in your school from the point of view of its acoustics.
15. Why is the use of mufflers required by law?
16. Explain the method by which mufflers eliminate sound.
17. How does resonance increase the intensity of the sound waves produced by a generator?
18. What is meant by the terms, *generator* and *resonator*, when applied to musical instruments?
19. Can you use resonance to explain the "shimmy" or "drumming" of an automobile?
20. Can you use interference to explain the decrease in vibrations when one increases the speed of an automobile over a "washboard" road?
21. Differentiate between the two kinds of resonators.
22. What is meant by the terms, *forced vibrations* and *sympathetic vibrations?*
23. Why are crowds in grandstands cautioned not to stamp their feet in unison?
24. Explain what is meant by the term *interference.*
25. Explain how depth-sounding devices using sound waves operate.
26. Explain the use of sound waves in geophysical prospecting.
27. What are echoes, and how are they produced?
28. Try to explain the rumbling of thunder.

UNIT VI

SECTION 9

SCIENCE AND ART HAVE JOINED HANDS IN THE PRODUCTION OF MUSIC

Introduction.

Music undoubtedly gives greater pleasure to more people than does any other art, and it can be even better appreciated or enjoyed if one knows something about the scientific basis of its production. Just as the painter uses the knowledge of light and color to express his emotions, so the musician applies his knowledge of sound to express his feelings. Modern advances in color photography have changed the emphasis and functions of painting, and, similarly, electrical musical instruments are providing new tools and creating new problems for musicians.

Sounds Are Classified as Noise and Tones.

The ear classifies sounds roughly into two classes: **noises**, which are disagreeable or irritating, and **tones**, which are received with pleasure or indifference, depending on the circumstances. Tones or any combination or succession of tones which are received with pleasure are said to be musical. There is no sharp borderline between a noise and a tone. Sounds classified as tones by some people are considered to be noise by other people. Noise is generally a sound of too short duration or of too great complexity to be analyzed by the ear. The best of music, or even any sound at all, gives the sensation of noise when the ear is too fatigued to analyze further sounds of any kind. Lack of training causes people to classify certain kinds of music as noise. Thus a "jazz" orchestra, Chinese music, or an African dance is disagreeable to people who have not learned or perhaps have not wanted to learn to appreciate such combinations of sounds.

A pure tone, produced by a simple vibration with no overtones, is unusual. Pure tones may be obtained with tuning forks, certain weak (stopped) organ pipes, or a flute or French horn softly blown. Most musical tones are rich in overtones. When the overtones predominate, the tone is likely to be strident or harsh. Tones are sounds

of such continuity and definiteness that their characteristics may be appreciated by the ear. The characteristics of musical tones discussed in Section 7 of this Unit may now be summarized in the following table:

CHARACTERISTIC	DEFINED AS	DEPENDS UPON
Pitch	Highness or lowness (position on the musical scale)	Frequency
Loudness (Intensity) .	Intensity of compressional waves	Inversely proportional to the square of the distance and directly proportional to the amplitude
Quality	Richness or timbre	Nature of instrument and the number and relative intensity of its overtones

Only a Limited Number of Intervals Are Musical.

In music *the ratio of the frequencies of two notes* is called the *interval* between them. If the number of vibrational cycles or compressional waves per second is doubled, an increase in pitch called the *octave* is recognized; additional doubling of frequencies gives rise to still higher octaves. The *octave* is *a musical interval of 2 : 1.* A difference in pitch of two tones produces a number of beats which depends upon the difference in pitch. Complex intervals produce tones which are unpleasant because the number of beats is increased to an extent that they cannot be differentiated by the ear.

The most common musical intervals are:

Unison	1 : 1	Minor third	6 : 5
Octave	2 : 1	Major sixth	5 : 3
Fifth	3 : 2	Minor sixth	8 : 5
Fourth	4 : 3	Major second	9 : 8
Major third	5 : 4	Major seventh	15 : 8
		Semitone	25 : 24

One who has no musical training or ability can make sounds with a musical instrument, but he cannot produce music because he does not know what combinations of sounds will produce musical tones and also because he has not developed skill in producing these sounds.

Sharps and Flats Make Possible All the Major Scales.

If a siren disk is made with four rows of holes consisting of 24, 30, 36, and 48 holes to a row, respectively, and the disk is rotated uniformly while a jet of air is blown through first one row of holes and then another, the familiar do-mi-sol-do scale will be produced. Any series

of four tones in the ratios of 24 : 30 : 36 : 48 produces *major chords.* A scale constructed on these ratios will have the following frequency ratios:

C Scale

Ratios . . .	1	9/8	5/4	4/3	3/2	5/3	15/8	2
Keys . . .	C	D	E	F	G	A	B	C
Frequencies .	256	288	320	341.3	384	426.7	480	512

These eight notes constitute an octave in the *scientific scale*, and the scale is said to be *diatonic.* The intervals between two successive notes are not equal but have the values

$$9/8,\ 10/9,\ 16/15,\ 9/8,\ 10/9,\ 9/8,\ 16/15.$$

Now suppose that we construct another scale, called the D scale, as follows:

D Scale

Ratios . . .	1	9/8	5/4	4/3	3/2	5/3	15/8	2
Keys . . .	D	E	F	G	A	B	C	D
Frequencies .	288	324	360	384	432	480	540	576

Comparison of Frequencies in the C and D Scales

	C	D	E	F	G	A	B	C	D
C Scale .	256	288	320	341.3	384	426.7	480	512	
D Scale .		288	324	360	384	432	480	540	576

A comparison of the C and D major scales shows some discrepancies; for example, F is 341.3 cycles on the C scale but 360 cycles on the D scale. If one were playing the D scale on a piano in which the keys were all tuned to the C scale, the F on the D scale would obviously lie about midway between F and G on the C scale. In order to make it possible to play all the scales (C, D, E, F, etc.), the black keys were added to provide for frequencies lying between those on the C scale. These "in-between" frequencies are called sharps and flats.

The International Scale Is Different from the Scientist's Scale.

The *Scientific Scale* of pitch uses 256 cycles per second as the standard for middle C, as compared with 258.7 cycles per second on the *International Scale.*

When we compare the frequencies of E on the C and D scales above, it is seen that on the C scale E is 320, while it is 324 on the D scale. To make possible the major scale in each key would require so many notes that musical instruments would be too complex for the average person to play. In order to avoid the difficulty of having two different frequencies to represent one note, the international or equal-tempered scale was devised. In this scale middle C represents a frequency of 258.7, and the frequencies for each of the thirteen tones in each octave are equally spaced. The equal-tempered scale produces a pitch for each key that is not ideal for best harmony, but the difference between the ideal pitch and the actual pitch can scarcely be recognized by the human ear.

Keyboard	Physical Pitch	Equal-Tempered
B	960.0	976.5
A	853.0	870.0
G	768.0	775.1
F	682.6	690.5
E	640.0	651.8
D	576.0	580.7
C	512.0	517.3
B	480.0	488.3
A	426.6	435.0
G	384.0	387.5
F	341.3	345.3
E	320.0	325.9
D	288.0	290.3
C	256.0	258.6
B	240.0	241.1
A	213.3	217.5
G	192.0	193.8
F	170.6	172.6
E	160.0	162.9
D	144.0	145.2
C	128.0	129.3

FIG. 222. A comparison of the Scientific and International Scales.

How Musical Instruments Produce Sounds.

As already pointed out, all musical instruments consist of two parts: the generator and the amplifier. The generator supplies the energy and fixes the frequency, while the amplifier enlarges the sound by forced vibration or resonance. There are two main types of instruments: the stringed instruments and the wind instruments.

Stringed Instruments. The generator in stringed instruments consists of strings or wires which are bowed (as in the violin), plucked (as in the harp or violin), or struck with a hammer (as in the piano) in order to produce the vibrations. The amplifier in such instruments may consist of a hollow wooden body (as in the violin) or a sounding board (as in the piano).

The different frequencies are produced in stringed instruments by the use of strings of different length, diameter, and tension. The heavier strings are wrapped with wire in order to provide inertia without impairing their flexibility. The piano and the harp contain many strings of fixed length, diameter, and tension, whereas other stringed instruments contain only a few strings whose effective length can be

altered by the musician's pressing down on the strings at various positions.

The strings in stringed instruments lose their tension by use and by changes in temperature and, therefore, have to be "tuned" frequently.

The laws of vibrating strings may be summarized as follows: the pitch is

1. Inversely proportional to the length.
2. Directly proportional to the square root of the tension.
3. Inversely proportional to the square root of the linear density.

Another way of expressing these laws is as follows:

Long, loose, large (thick and dense) strings produce low pitch.
Short, stretched, small (thin and not dense) strings produce high pitch.

Wind Instruments. There are two kinds of instruments which are operated by wind. In the first type only the air vibrates, while those of the second type require a mechanical vibrator such as a reed or the player's lips. All wind instruments contain air columns which amplify by means of resonance. Such resonators can emit only their fundamentals or one or more of their harmonic overtones. Bugles produce different pitch by changing the position of the lips and changing the force of blowing, much as whistling with the lips is accomplished. Different notes in other wind instruments are obtained by changing the length of the resonator. This may be accomplished by opening side holes, as in the flute and clarinet, by use of valves which insert additional lengths of tubing, as in the cornet, or by sliding tubes as in the trombone.

It is interesting to note that the tones produced by wind instruments depend somewhat on the nature of the materials from which the instruments are made.

The clarinet generates sound by means of a single reed which vibrates against the opening in the mouthpiece, while the oboe has a mouthpiece consisting of two reeds which vibrate against each other.

The slender conical tube of the horn may sometimes be more than eighteen feet long. Very long, straight horns are used by the Chinese, but the majority of horns are made spiral-shaped in order to increase the ease of handling. Cones in wind instruments provide the overtones that help to determine the quality of the tones produced. The lips of the musician serve as the generator in the horn, the bugle, the trombone, and other similar instruments.

Harmonicas and accordions produce their tones by causing many thin metal reeds to vibrate with a column of air.

If a set of similar stoppered test tubes are filled to different heights with water, tones of different pitch will be obtained when the stoppers are pulled out from each tube. In this experiment the vibrations are set up by the rapid expansion of the air produced by removing the stopper. The amplifier is the column of air in the tube, which, by resonance, produces tones whose pitch depends on the length of the air column. Similar differences in pitch can be produced by filling tumblers to varying heights with water and striking them with a knife, for example.

The sounds produced in this way do not last long enough to give good musical tones. Continuous notes can be obtained, however, by blowing across the tops of test tubes.

In organ pipes and whistles there are channels to guide the air up to and across the mouth of the pipe.

Air columns are found to give the maximum sounds for vibrations of certain frequencies only. This is explained by the fact that sound waves reflected back in a tube may interfere with incoming waves, so that little or no sound is produced unless the incoming wave is of such a frequency that it is reinforced by the reflected wave; the column of air will be caused to vibrate with this frequency, producing an intense sound. There is a distinct relationship between the length of the tube and the frequency of the vibration. This accounts for the differences in the lengths of organ pipes.

In most wind instruments tones of higher pitch, the overtones, may be obtained by increasing the force of the wind; however, in organs, the wind is delivered at fairly constant pressure, so that these variations in pitch are taken care of by a multiplicity of pipes of different sizes. Some organs have as many as 30,000 pipes.

Drums, cymbals, bells, xylophones, triangles, and similar instruments depend on vibrations, often of a very complex nature, produced in rods, membranes, and plates by a blow.

The quality of different musical instruments is determined by the loudness and pitch of the overtones. It is quite possible to analyze the tone produced by any musical instrument and to determine the loudness and pitch of each of the overtones present. The Novachord is a musical instrument that is capable of producing and regulating the loudness of a large number of overtones along with the fundamental musical tones.

The Novachord is capable of closely imitating the majority of musical instruments. About six hundred radio tubes are used in the Novachord. Nearly perfect imitations of musical instruments could be produced by instruments based on the principle of the Novachord

but capable of producing many more overtones. Such instruments would be so complex and so expensive, however, that few people could afford to purchase them.

The Novachord uses vacuum tubes to produce electrical waves that are changed into sound just as radio waves are changed into sound in the radio loud-speaker. The Hammond Electric Organ uses synchronous motors to turn iron cogs near coils on magnets which thus generate alternating currents which are then converted into sound by the system used in a radio. In 1939 Hammond added a synthetic reverberation unit which gives the effects of a large organ in an auditorium.

The Solovox is an inexpensive electrical musical instrument designed to supplement the piano by providing tone qualities which the piano cannot produce.

The Human Voice Is the Most Versatile of Musical Instruments.

The human voice is a reed type of instrument. The vocal cords act as the generator; and their tension, length, and thickness can be controlled by the muscles. The vibrations are produced by the flow of air controlled by changing the size and shape of the throat cavities and by closing and opening the lips. The amplifier consists of those cavities whose shape markedly affects the quality of the tones produced.

STUDY QUESTIONS

1. What is music as differentiated from noise?
2. Why is it that some people can produce music from a given instrument while other people cannot do so?
3. How does the human voice produce sounds?
4. Why are some voices musical, while others are not?
5. What principles are used in different musical instruments — wind, string, drums, tympani — to produce sounds?
6. Ask some of your musical friends to explain the difference between grand and upright pianos and between cheap and expensive pianos.
7. Try to find out the difference between Occidental and Oriental music.
8. Upon what factors do pitch, intensity, and quality of sound depend?
9. What are two important parts of nearly all Musical instruments?
10. What does the elimination of overtones do to sound?
11. What does the musician mean by the terms, *harmony* and *discord?*
12. What does a violinist do to his violin in order to tune it?
13. How can a violinist produce so many tones with so few strings?
14. Explain how the Novachord imitates many musical instruments. Why does the Novachord fail to give perfect imitations of musical tones which are very rich in overtones?
15. What is the function of the Solovox?

16. How do the Novachord and Hammond Organ produce and control the pitch of musical tones?
17. In what respect could an orchestra, a band, or a choir be considered to be a supermusical instrument?
18. If a major chord begins on a tone whose frequency is 512, what are the frequencies of the other tones?
19. Explain the necessity for the black keys on a piano.
20. Account for the change in pitch as water is poured into a deep jar.
21. Explain the production of different tones with "musical glasses."
22. What is there in music that is not scientific?
23. Discuss the fact that a person with "absolute pitch" may not be musical.

UNIT VII

THE APPLICATIONS OF MAGNETISM AND ELECTRICITY HAVE GREATLY MODIFIED THE ACTIVITIES OF MANKIND

INTRODUCTION TO UNIT VII

No better illustration of the impact of Science on the activities of mankind can be found than magnetism and electricity. Suppose that all the sources of electric power were suddenly and permanently cut off; the results would be similar to those experienced in a large city in one of those very rare occurrences when the power is shut off for a few hours due to damage produced by an electrical storm. Streetcars cease to run, motion-picture theaters are darkened, stores and offices must close, elevators cannot operate, water cannot be pumped through the city's distribution system, and, in general, man would find himself reduced to the life of a backwoods farm, except that he would not be equipped with candles or kerosene lamps and would not have his own private well or spring to furnish water.

Modern civilization is built around electricity. Without electricity modern factories could not run; the radio, the telephone, and the telegraph could not exist. Many modern homes would not be prepared for heating, refrigeration, lighting, cooking, washing, ironing, cleaning, or ventilation if the electricity were to be cut off. Even motorcars and airplanes depend on electrical ignition systems.

In this Unit we shall study the development of knowledge concerning electricity and magnetism and show how it has been applied in the service of mankind. The revolution in living produced by the application of electricity has, for the most part, taken place during the lifetime of our parents and has become widespread within the lifetime of most of the freshmen in college today. This can be appreciated best by reference to the fact that the wholesale sale of energy increased from 3,254,000,000 kilowatt-hours in 1912 to 44,326,000,000 kilowatt-hours in 1929, or 1360 per cent. Since 1929 the consumption of electric energy has been steadily increasing.

UNIT VII

SECTION 1

MAGNETISM IS PRODUCED BY THE ORIENTATION OF MOLECULES

Introduction.

Magnetism has been known since the time of the early Greeks, but it was not until the past century that it was studied and put to useful application, except in the mariner's compass.

The ancient Greeks knew of the peculiar property of attracting bits of iron possessed by certain lustrous black stones brought from Magnesia in Asia Minor. They were named "magnets" because of their source. These stones were really pieces of an iron ore, now called "magnetite."

Later the miners on the island of Samothrace came to know that certain types of iron would become imbued with this property of magnetism when rubbed with magnetite.

It was discovered that a piece of magnetite suspended so as to turn freely about a vertical axis would always come to rest with the same part of the stone pointing in a northerly direction. This was the first magnetic compass, and the stone thus came to be known as "lodestone," or "leading stone." The origin of the compass is unknown, but it is certain that crude ones were in use during the latter part of the thirteenth century. These early compasses consisted of a magnetic needle supported so as to float on water. The invention of the compass was of outstanding significance, for it permitted mariners to undertake long journeys of exploration, adventure, and commerce.

Only a Few Substances Exhibit Magnetism.

This property, characteristic of certain uncharged substances, to attract others is called *magnetism*. Such objects are described as being *magnetic*. The only substances which exhibit magnetism to any considerable extent are iron, cobalt, and nickel. Iron is by far the most magnetic of all the elements, although certain alloys far surpass its magnetism — permalloy, an alloy of nickel and iron, and perminvar, an alloy of nickel, iron, and cobalt, are typical examples. A recent

iron alloy containing aluminum, nickel, and cobalt, hence called "alnico," is so powerfully magnetic when magnetized that it lifts 500 times its own weight. An alnico magnet constructed with many air gaps has supported 4450 times its own weight. Another alloy composed of vanadium, iron, and cobalt, developed by the Bell Telephone Laboratories, will hold more permanent magnetism than any other known material. A whole range of alloys of iron, nickel, chromium, and silicon can be prepared in such proportions that they will lose or regain their magnetism at certain definite temperatures from $-150°$ C. to $1100°$ C., thus providing a new method of producing automatic temperature controls.

The first serious study of magnetism seems to have been made by the physician, *Sir William Gilbert* (1540–1603), at the end of the sixteenth century. A unit of magnetism, the "gilbert," has been named after him. He noted that in England the needle of the mariner's compass dipped with its north pole downwards through an angle depending on the latitude, and he inferred from these experiments that the earth itself acts as a huge magnet, with its poles considerably distant from the geographical poles. Gilbert observed that the attraction of a magnet appears to be concentrated at two points which are called *poles*. In the case of bar magnets the poles are generally near the ends, as can be proved by dipping them in iron filings. William Gilbert is considered to have been the founder of the sciences of magnetism and electricity. *Francis Bacon* repeatedly referred to him as one of the first men to practice the experimental method.

Like Poles Repel and Unlike Poles Attract Each Other.

Gilbert made a small globe out of lodestone and found that it behaved much like the earth toward compasses. He found that what we call the north magnetic pole of the earth corresponds to the south pole of a magnet; north-seeking poles of magnets repel each other, while there is attraction between unlike poles. This is a very important law of magnetism, namely, that ***like poles repel and unlike poles attract each other***. The amount of their attraction or repulsion varies with the strength of the poles and inversely with the square of the distance between them — another example of the inverse square law. The ***north pole*** of a magnet is the end of the magnet that points toward the north pole of the earth.

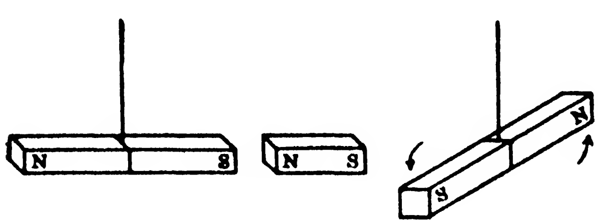


FIG. 223. Like poles are repelled while unlike poles are attracted by each other.

Magnets Are Surrounded by Magnetic Fields.

The fact that it is not necessary for magnets to touch each other in order for their attractive or repulsive force to act is accounted for by the hypothesis that the space around a magnet must be in a state of strain.

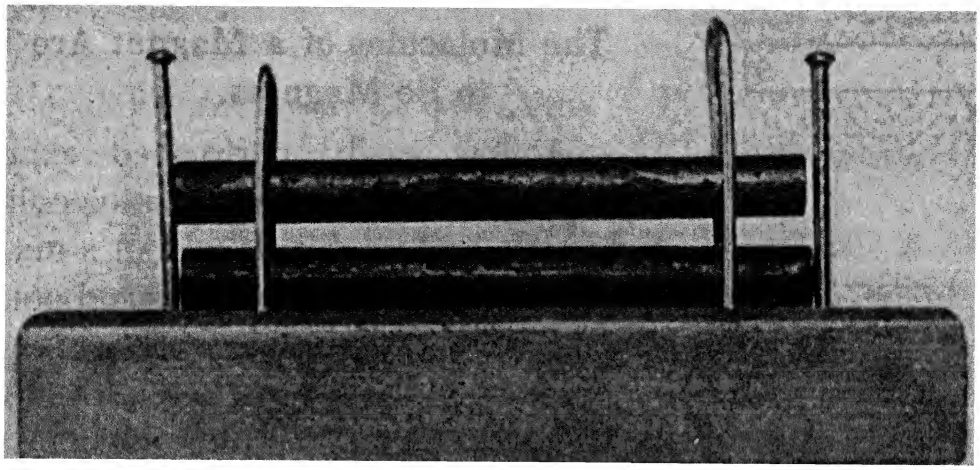


FIG. 224. A floating magnet. One magnet is held in position above the other magnet, because of the repulsion of like poles.

The region subject to this strain is called the *magnet's field*, or simply the *magnetic field*. A very good map of such a field can be obtained by placing a piece of paper over a magnet and then sprinkling iron filings over the paper; see Fig. 225. It will be noted that the complete *lines of force* (used to represent a magnetic field) extend from the north pole to the south pole or vice versa, and this would be found true of every line if one could follow it far enough, as indicated in Fig. 226.

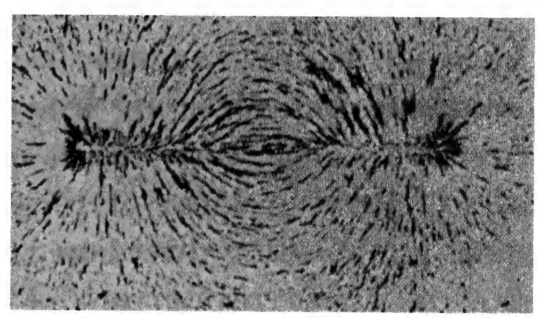


FIG. 225. Lines of force of a rod magnet as shown by iron filings placed on a sheet of paper above the magnet.

Michael Faraday (1791–1867), the experimenter who did more than any other man to place the science of magnetism and electricity upon a firm basis, found that these lines of force behave like stretched rubber bands, trying to shorten in the direction of their length and to widen in the direction of their width.

The Earth Is a Giant Magnet.

The poles of an ordinary magnet derive their names from their behavior toward the earth. Those that point north are called north poles. As we have already pointed out, the magnetic poles and geographic poles do not coincide.

A compass supported so that it can swing vertically is called a *dipping needle.* The dipping needle shows the direction of the lines of force in the earth. Large deposits of magnetic minerals alter the direction of these lines of force somewhat in certain localities.

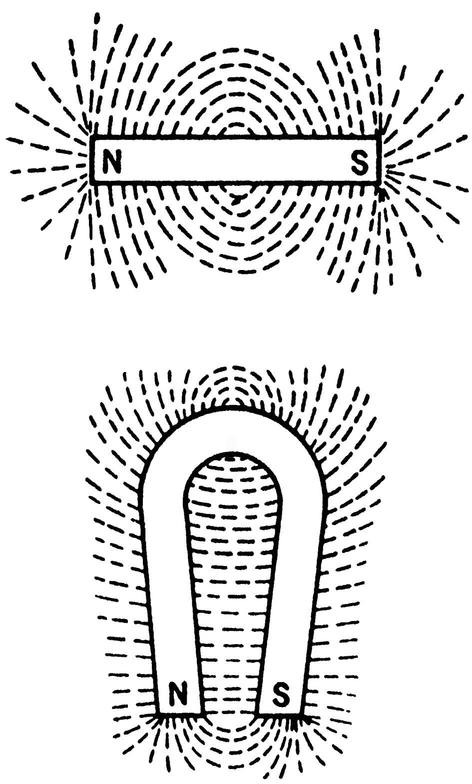


FIG. 226. Diagrammatic representation of the lines of force of typical magnets.

The Molecules of a Magnet Are Believed to Be Magnets.

A few easily performed experiments show that magnetism is molecular in its nature and origin. If we cut a magnetized steel wire showing pronounced poles at the ends into short pieces, each one of these pieces will be a magnet with north and south poles. This subdivision into separate small magnets can be continued until the pieces are too small to be further subdivided by physical methods. Such experiments form the basis for the molecular theory of magnetism. According to this theory, each of the particles (atoms or molecules, or groups of these, as the case may be) of which the iron wire is composed is a tiny magnet having a north and a south pole. In an unmagnetized piece of iron these small magnets point in various directions with no resultant magnetic effect. Magnetizing of iron consists of turning some of these miniature magnets so that their poles point in the same direction and therefore unite to make the whole bar show magnetic properties. The above process of aligning the particles is called *orientation.* The molecular theory seems to be quite logical when we consider how a bar of iron is magnetized. One way of magnetizing a body is to stroke it with a magnet, always drawing the magnet the same way on the bar. Another way is to hold the bar so that the earth's lines of force pass through it, and to tap it several times. On the other hand, a magnet may be demagnetized by tapping it while it is held in such a position that the earth's lines of force do not pass through it lengthwise. Still another method of destroying the magnetism of an iron bar is to heat it to redness.

All these phenomena can be explained by the molecular theory. Stroking with a magnet tends to orient the molecules. Tapping temporarily disturbs the forces which hold the molecules together within the solid, thus leaving them free to rearrange themselves in accordance

with the forces acting on them. Heating agitates the molecules so much that all previous orderly arrangements are broken up and thus destroys the magnetism. The molecular theory can be demonstrated very nicely by stroking a test tube full of iron filings with the pole of a magnet. The iron filings are found to line up end to end, but this orderly arrangement may be disturbed by shaking the tube.

The molecular theory may also be demonstrated by suspending a large number of small magnets on pivots on a board and submitting them to magnetic fields. The small magnets will spin around as a large magnet is moved over them, or they will become oriented when one pole of the magnet is placed at one end of the board.

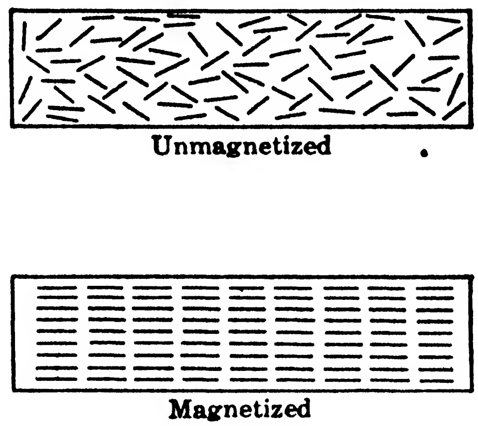


FIG. 227. The molecules are thought to be oriented when the bar of iron is magnetized. The molecules in the unmagnetized bar are not oriented, while those in the magnetized bar are oriented.

The methods described above for magnetizing a piece of iron are examples of what is known as *magnetic induction*. The molecules of soft iron are easily oriented according to the above theory, inasmuch as soft iron acts as a magnet only when it is in a magnetic field; for example, a piece of soft iron held near a magnet acquires the property of picking up iron objects but loses it at once when the magnet is removed. A whole chain of tacks can be picked up by a magnet because each tack temporarily becomes a small magnet by induction. Steel is more difficult to magnetize but retains its magnetism for a long time once it is magnetized. According to the molecular theory the molecules in steel are held together more rigidly than are the molecules in soft iron.

A magnet is said to be saturated when it can acquire no more magnetism, or, in other words, when the maximum fraction of the molecules has been oriented.

A magnetic field can freely penetrate nonmagnetic substances such as paper, wood, or glass. Some substances are more readily penetrated by magnetic fields than others. Thus iron has a permeability (attraction for lines of force) several hundred times that of air. This is shown by the bending of the earth's lines of force as they pass over a deposit of iron ore. In some parts of the world the compass is rendered useless for telling directions because of the attraction of large deposits of magnetite for the compass needle.

The magnetic field in the gap of a broken ring is very intense. This fact is applied advantageously in the use of horseshoe magnets.

The molecular theory does not explain magnetism but merely indicates that magnetism is a molecular phenomenon.

Magnetism Is Now Explained by the Electron Theory.

Undoubtedly you have already wondered what iron has that copper or lead do not have as far as magnetism is concerned. According to the Bohr theory of atomic structure, the atom is a miniature solar system in which electrons (negative charges of electricity) revolve about a positively charged nucleus. (The meaning of negative and positive charges will be discussed in the next Section.) These electrons also spin about their own axes. Later we shall learn that electrons in motion are surrounded by magnetic fields, *i.e.*, that electrons in motion behave like magnets. The electrons in an atom create two magnetic fields, one for their orbital motion and one for their spin. It is the spin that causes each electron to behave like a small bar magnet. In many atoms the electrons spinning in a clockwise direction cancel the magnetic effects of the electrons spinning in a counterclockwise direction. In iron and other magnetic substances the electrons spinning in one direction exceed the number of electrons spinning in the other direction, and magnetism results. The above theory is based upon considerable experimental evidence, but it has not been proven to be correct.

Magnetism Tells the "Lay of the Land."

The petroleum geologist is aided in petroleum exploration and development by a knowledge of the direction and inclination of underground rock layers. An ingenious method of obtaining this information consists in slowly revolving near suspended magnetic needles a core obtained in drilling the well. When the needles are attracted or repelled, their movement is photographed. The permanent magnetism in the core's minerals resulting from lying in the earth's magnetic field for millions of years shows which part of the core had faced north.

STUDY QUESTIONS

1. Describe the circumstances that seem to have led to the discovery of magnetism.
2. Describe a simple compass.
3. How can the magnetism of a magnet be destroyed?
4. Why can the magnetic compass not be used in some regions of the earth?
5. What makes a freely moving magnet point north and south?
6. How may an iron bar be magnetized?
7. If an iron bar is easy to magnetize, will it retain its magnetism for a long time?

8. Explain the magnetizing and demagnetizing of an iron bar in terms of the molecular theory.
9. Why does a dipping needle not dip to the same degree at different points on the earth's surface?
10. What is the difference between an unmagnetized and a magnetized iron bar according to the molecular theory?
11. Explain how magnetism may be increased by rhythmical pounding.
12. Give the facts of magnetism, and show how the molecular theory explains each fact.
13. Give the laws of magnetism.
14. How can you prove that the earth is a magnet, *i.e.*, (*a*) that it has two poles, and (*b*) that it is surrounded by a magnetic field?
15. Try to explain the laws of magnetism in terms of the molecular theory.
16. What examples of the inverse square law have we studied up to date? Look up the inverse square law as it applies to sound energy, and on the basis of the explanation given, try to work out an explanation for the inverse square law as it applies to magnetism.
17. What metals compose the alloys which are used to make powerful permanent magnets?
18. Give an example of induced magnetism and explain it.
19. Give the facts that support the molecular theory of magnetism.
20. Distinguish between a *magnet* and a *magnetic substance*.

*

UNIT VII

SECTION 2

STATIC ELECTRIC CHARGES MAY BE PRODUCED BY FRICTION OR INDUCED BY AN ADJACENT CHARGED BODY

Introduction.

A type of repulsion and attraction between bodies at a distance, which in some ways resembles the attraction and repulsion of magnetic poles, is that between electrified bodies. Electric charges may be produced by friction between surfaces. Unless the air is fairly dry, these charges will not accumulate to a point where they will produce striking effects, because films of moisture enable them to be conducted away. There are many well-known examples of electrification by friction. Many people, having shuffled across a rug on a dry day, have produced an electric spark as they touched their fingers to an iron bed, a radiator, water pipe, or any other metallic object. The electric charge in this case is produced by the sliding contact between the shoes and the rug. This effect is more pronounced when the atmosphere is dry than when it is humid. The crackling and standing on end of dry hair when a comb is drawn through it is a common experience. Explosions have resulted from the spark produced by the friction of gasoline flowing through a pipe, and special precautions are now taken to prevent such explosions.

Static charges may be produced by friction or they may be induced by a nearby charged body. An induced charge is the charge acquired by a neutral body when it is brought near a charged body. The explanation of this phenomenon will be given later.

There seems to be very little connection between magnetism and static electricity except that both are related to current electricity. The great value of a knowledge of static electricity lies in the fact that it forms a necessary foundation for the understanding of current electricity.

Static Phenomena Have Been Known for a Long Time.

Thales (640–560 B.C.) discovered that amber, when rubbed with a woolen cloth, acquired the power to attract to itself light objects such

as bits of paper, pith, or straw. The Greek name for amber was ἤλεκτρον, which, transliterated into English, is "elektron."

At the beginning of the seventeenth century, *William Gilbert* (1540–1603), court surgeon to Queen Elizabeth, repeated Thales' experiments and found that other materials would behave like amber. Glass and sealing wax were found to acquire the property of attracting certain objects when they were rubbed. Gilbert could not explain the phenomenon, but he did name this new form of energy "electric," after the Greek word for amber. From this term our modern word "electricity" was derived.

Two Kinds of Electrification May Be Acquired by Friction.

Hard rubber, sealing wax, or a glass rod will acquire this power of "electric" attraction when rubbed with wool, fur, or silk.

If we bring a glass rod, charged by rubbing with silk, near a pith ball suspended by a silk thread, the pith ball will be attracted to the rod, and upon touching it, will be vigorously repelled. Another pith ball will behave similarly when it is brought into contact with a hard-rubber rod which has been previously rubbed with a woolen cloth. These two pith balls will now be found to have an attraction for each other. It will also be found that each pith ball is attracted by the rod used to charge the other pith ball. If the two charged pith balls are allowed to touch each other, they lose their charge, *i.e.*, their ability to attract or repel each other.

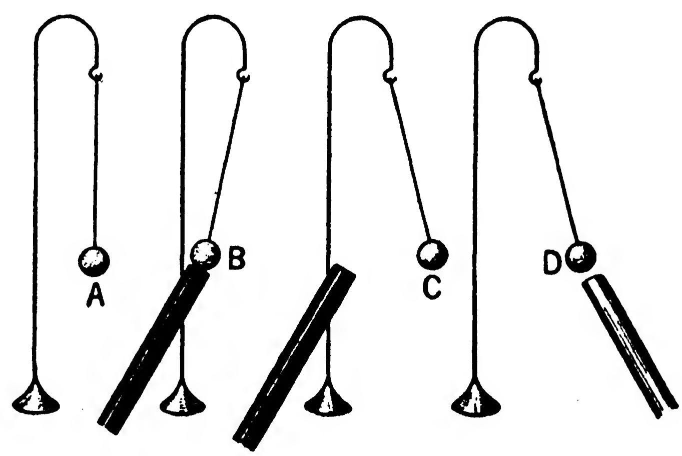


FIG. 228. The hard-rubber rod attracts a pith ball in B, but upon touching it, repels it as shown in C. The pith ball repelled by the rubber rod is attracted by a glass rod that has been charged by rubbing it with silk as shown in D.

It would appear that *there are two kinds of electrification and that like kinds repel each other whereas unlike kinds attract each other.*

Static Charges Are Produced by a Gain or Loss of Electrons.

According to the electron theory, all material objects are composed, in part at least, of discrete positive and negative charges of electricity. A neutral body possesses the same number of positive charges (protons) and negative charges (electrons). A negatively charged body possesses an excess of electrons, whereas a positively charged body possesses

an excess of protons. It is a fundamental concept of our modern electrical theory of matter that opposite charges attract each other, whereas like charges repel each other.

It is easy to explain by the modern electron theory the phenomena just observed. According to this theory, glass, when rubbed by silk, loses electrons and therefore becomes positively charged. On the other hand, hard rubber, when rubbed by wool, gains electrons from the wool and therefore becomes negatively charged. The pith ball, when touched by the glass rod, is repelled because it gives up some of its electrons to the glass rod; and, thus becoming positively charged, the ball is repelled by the glass rod, which still possesses an excess of protons.

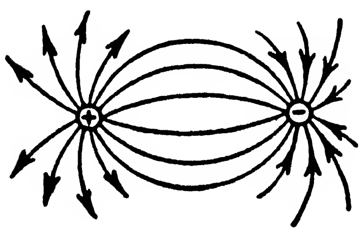


FIG. 229. The lines of force in an electric field between two opposite charges.

The concept that electrostatic fields surround all electric charges is very useful in explaining many phenomena. The imaginary lines of force radiating in all directions from a single electric charge, either positive or negative, terminate on other opposite charges. Figure 229 shows the field between two opposite charges. The conception of tension along these lines and of a compression at right angles to them, explains electric attraction and repulsion, just as it served to explain magnetic attraction and repulsion using magnetic lines of force.

A Static Charge May Be Induced by Bringing a Charged Body Near an Uncharged Body.

Perhaps you have already raised the question: why was the pith ball originally attracted to the charged rod? This is explained by assuming that the charges on the pith ball corresponding to the charge on the rod were driven to that surface of the pith ball farthest away from the rod, thus leaving an excess of opposite charges on the nearest side.

This idea can well be illustrated by the electroscope. The electroscope is an instrument used to identify and indicate the charge on a body. One form of the electroscope consists of a pair of gold leaves suspended in a metal box to shut out air drafts, and provided with windows to look through.

If a charged rod is brought near the electroscope, the leaves will repel each other because they acquire a like charge by induction. This charge is not permanent, however, for the electrons have only shifted their position in the leaves and have not been transferred to another object. When the charged rod is removed, the leaves fall back next to each other.

If the outside knob of the electroscope connected directly with the leaves is touched by the charged rod and the rod is again removed, the leaves diverge and do not fall back again. If one places his finger on the knob and then removes it while the charged rod is still in contact with the knob, the leaves will fall; but when the rod is removed the leaves will diverge and remain apart for some time. In this case, the charge induced on the leaves has been transferred to the body, with the result that the leaves have an excess or deficiency of electrons, as the case may be. An electroscope can thus be charged with a known charge and be used to determine the charge on another body, because a like charge brought near the electroscope will produce greater deflection, whereas an unlike charge will decrease the deflection.

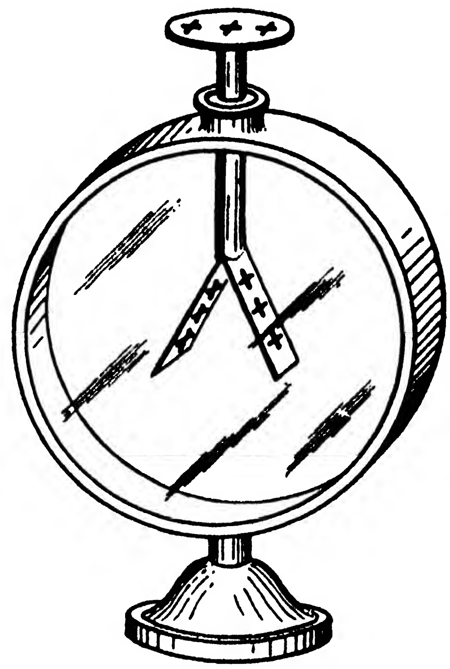


FIG. 230. A gold leaf electroscope.

Only Insulators or Insulated Bodies Can Be Charged.

If one tries to charge metals by rubbing them, he will find upon testing them with the electroscope that they cannot be charged as long as they are held in the hand but that they can be charged when held by glass or hard-rubber handles because metals conduct electricity, while glass and hard rubber do not. Substances which conduct electricity are called *conductors*, while those which do not conduct electricity are called *nonconductors*, or *insulators*. The electrons in the atoms of nonconductors are thought to be held too tightly within the atoms to move freely, while the electrons in conductors are relatively free to move. All metals are good conductors, although some are better conductors than others. Silver, copper, gold, and aluminum, in the order given, are the best conductors. Sulfur, a nonmetal, is a very poor conductor.

Charges Distribute Themselves on the Surfaces of Objects.

Charges are found to be distributed on the surfaces of objects. The electrical force of repulsion between like charges causes them to get as far away from each other as possible. The force between these charges varies inversely as the square of the distance between them.

If a charged rod is brought near two conductors mounted on insulating bases and in contact with each other, electrons will be driven to one

of the conductors. If the conductors are now separated without moving the rod, they will be found to have opposite charges.

Charges are distributed uniformly only if the surface is smooth and flat or uniformly curved; on other surfaces the charges collect at the more pointed portions. Electrons concentrate on sharp points and cause the air to become ionized; that is, molecules of air become charged and thus conduct the electrons from the point.

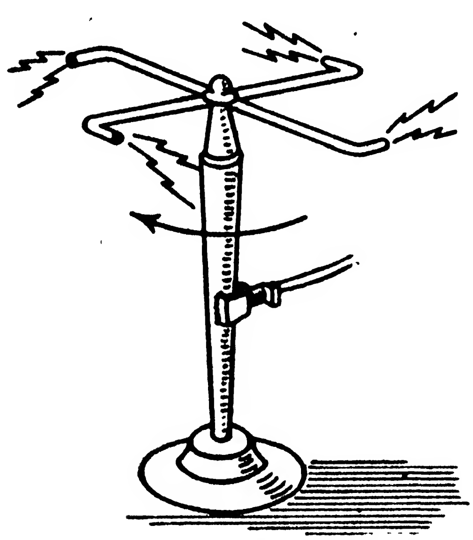


FIG. 231. The electric whirl.

Sometimes this discharge at the tips of lightning rods, flag poles, or masts of ships produces a faint violent glow, called "St. Elmo's Fire," that can be seen at night. Similar discharges along high-voltage electrical transmission lines are called "corona" discharges. The ions repelled from the charged body create a wind which is capable of blowing a candle flame out of shape. The "electric whirl," which is based on the principle of the Fourth of July pinwheel, or rotary lawn-sprinkler, is also produced by a similar repulsion of ions from a charged body.

In operating the Van de Graaff electrostatic generators, to be described later, the operators are housed within the charged spheres for protection against possible harm from the tremendous voltages produced, for charges cannot remain on the inner surface of the cage.

Lightning Is a Static Phenomenon.

As previously mentioned, lightning is the discharge between a cloud and the earth. The source of the charges is not thoroughly understood, although it is generally believed that it is produced by the intense friction and splitting of large raindrops brought about by the rapidly rising currents of air so characteristic of thunderstorms. The rising currents of air may possibly produce differences in charges due to the fact that the lower atmosphere is positively charged relative to the upper atmosphere. Very possibly the charge is also produced by the rapid condensation of moisture in such storms, the charges being concentrated on smaller total areas and thus producing higher potentials.

Negative charges concentrate on the bottoms of clouds, leaving the tops positively charged. Discharges may take place between the top and bottom surfaces of adjoining clouds.

A charged cloud may induce an opposite charge on the nearest portion of the earth. This induced charge will concentrate on trees, flag

poles, or buildings which rise above the surface of the ground and thus act as pointed surfaces. Eventually this charge may become so great that the resistance of the air is overcome and a lightning flash occurs. To protect an object against lightning, metal rods with sharp points are used to discharge the induced charge. Such lightning rods must be well grounded in the earth, and it is generally recommended that they be connected with some object such as a copper boiler buried in the deeper damp earth. Static charges which cause sheets of

FIG. 232. Three million volts of laboratory lightning striking a car in the Westinghouse high voltage laboratory. The bolt can be seen jumping over the left front wheel to reach the ground. (Courtesy of the Westinghouse Electric and Manufacturing Company.)

FIG. 233. Lightning striking the Empire State Building, New York City. Although this building has been struck by lightning many times, no harm was done to the building because its steel framework acts as a Faraday cage. (Courtesy of the General Electric Company.)

paper to stick together while using a mimeograph machine may be discharged by draping Christmas-tree tinsel over the machine. Gasoline trucks drag chains on the ground to prevent the accumulation of static electricity that might produce a spark and ignite the gasoline.

The United States Census reports show that nearly two thousand people are killed or injured by lightning each year.

When one is caught out of doors in a thunderstorm, he will be safe under a well-grounded iron bridge. In a violent storm he should sit down or lie down in a hollow spot away from trees or fences. In woods, seek shelter under the smaller trees. Do not go in swimming during a lightning storm.

If a house could be enclosed in a Faraday cage of ironwork, the house would not be struck by lightning, and the cage could be struck repeatedly without producing any observable effect. Modern steel-framed skyscrapers with their foundations sunk deep into the wet ground constitute such cages. Such structures are often struck by lightning, but there is no record of anyone ever having been harmed in the process. Similarly, a cage of cables is very effective for smaller dwellings as a protection against lightning.

The passage of lightning through the air raises the temperature of the air and thus causes such a great expansion of gas in a small amount of time that compressional waves are produced similar to those produced by a tremendous explosion, thus producing thunder.

Machines Have Been Invented to Produce Static Electricity.

Static electricity may be produced by means of various electrostatic machines, such as the Wimshurst machine, which consists of many strips of tin foil mounted on a nonconducting disk. These disks are rotated and produce charges by induction. The charges are collected by metallic brushes and carried to a Leyden jar, where they are stored. The principle of the Leyden jar will be discussed in the following description of condensers.

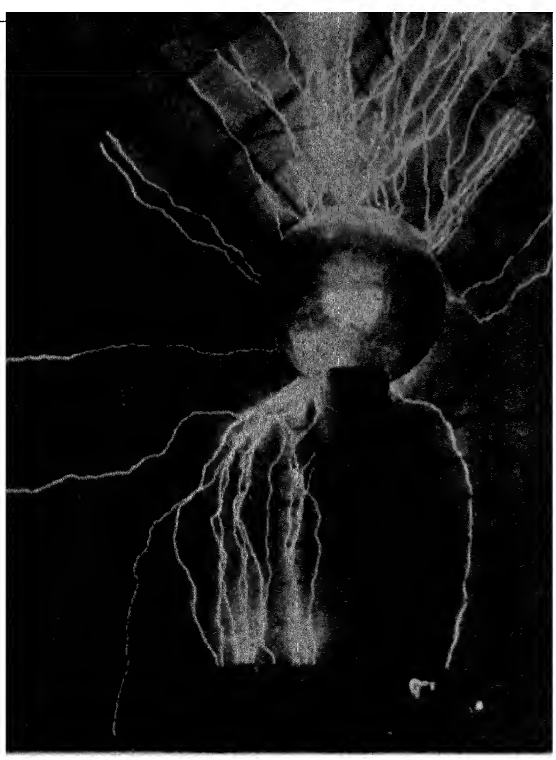


FIG. 234. Artificial lightning produced by the Van de Graaff generator. (Courtesy of the Massachusetts Institute of Technology.)

The production of static electricity by induction has been carried out on a large scale by Van de Graaff of the Massachusetts Institute of Technology.

The 10,000,000-volt generator constructed by Van de Graaff consists of two large hollow columns, 25 feet high and 6 feet in diameter, surrounded at the top by hollow polished aluminum spheres 15 feet in diameter. Each column is supported on a heavy four-wheeled truck running on a railroad track 14 feet wide. Inside of each ball is a pulley, and a corresponding pulley is mounted on the shaft of a motor at the bottom of the column. A silk belt travels around these pulleys. A 10,000-volt transformer-rectifier set is used to deliver a 10,000-volt direct current to the belts by means

of comblike contacts set close to the belt. The electric charge thus induced on the belt is conveyed to the hollow spheres, where it travels to their surface. The belts can also create and convey the electric charge without the use of the lower-voltage current, for, when once started, the charges are built up on the belts by friction. When the voltage in the aluminum globes has been built up high enough, miniature lightning bolts can be produced with these generators. It is perfectly safe for the operators to carry out their experiments in their small laboratories within the globes.

When the generator operates at its full capacity it should generate as much power as the power plant of a small town, for it would light 90,000 ten-watt, 110-volt incandescent electric lamps if connected in series.

Condensers Are Used to Store Static Electricity.

Condensers are merely pairs of conductors separated by nonconductors. One of these conductors may be connected to the earth. If a charge is now induced on the other plate, opposite charges are carried by the grounded plate. These charges become larger than would otherwise be possible because the charge on the one plate partially overcomes the repulsion between the opposite charges on the other plate. The charges thus become *condensed.* If too large a charge is placed in a condenser, the air will become ionized and a spark will occur. A much larger charge may be placed in a condenser if the conductors are separated by some medium such as oil or glass, rather than air. A "Leyden jar" is simply a condenser in which a glass bottle separates the two conductors of a condenser. The jar is usually coated on each side with tin foil. The Leyden jar was invented by *Pieter van Musschenbroek,* a professor at the University of Leyden, in 1746. Charged Leyden jars can produce tremendous shocks and must be handled carefully. Van Musschenbroek's discovery was based on a shock which he received when he touched with one hand a bottle of water connected to one terminal of an electric machine and touched the other terminal with his other hand. He received such a shock that he said, "I would not take another for the kingdom of France."

One time Benjamin Franklin entertained some of his friends with a turkey dinner. The turkey was killed by the discharge from ten Leyden jars and was roasted by a fire kindled by a similar discharge. Benjamin Franklin (1706–1790) was not only a statesman but also a scientist. He is famous for the experiment in which by means of a kite he drew down sparks from the clouds during a thunderstorm, thus showing the similarity between lightning and electrostatic

phenomena produced in the laboratory. Franklin devised an ingenious method of causing an approaching thunderstorm to announce its presence so that he could try out further kite experiments. He hung a small metal ball by a silk thread between two small bells. An approaching storm induced opposite charges on the two bells. The ball obtained a charge from one bell and was then repelled to the other bell, which neutralized the charge and gave the ball an opposite charge which repelled the ball again. The repeated attraction and repulsion caused the ball to ring the bells as it swung back and forth. It was Franklin's suggestion that lightning rods with sharp points be used for the protection of buildings. Franklin also made the first bifocal glasses, suggested watertight compartments for ships, and invented the stove still known by his name.

Difference in Potential Is Essentially the Amount of Work Required to Carry a Unit Charge from One Body to Another.

Tremendous differences of potential may be built up between the earth and thunderstorm clouds because so much power is required to pass an electric current through such long distances in air. The unit of potential difference is the *volt*, often called the *statvolt* when referring to static electricity.

A potential difference of about 30,000 volts is required for each centimeter of distance in order to cause an electric discharge through air.

There Are Several Important Applications of Static Electricity.

Two important practical applications of static electricity are the Cottrell Process, described on p. 726, in which charged smoke particles are attracted to oppositely charged plates in smoke stacks, and a similar device, the precipitron, which removes a very high percentage of dust and other suspended matter from the air. The precipitron first induces a charge on the particles and then precipitates the particles by attracting them to charged surfaces.

In 1926 the Norton Company discovered that the cutting property of sandpaper could be improved by 20 to 50 per cent by causing the sand particles to stand upright by passing them through an electrostatic field before the adhesive is dried. This company coöperated with the Arnold Print Works in developing a similar method to produce simulated embroidered cloth by "printing" an adhesive on cloth and then causing short cut fibers to cling to the adhesive in an upright position by means of electrostatic charges.

STUDY QUESTIONS

1. Explain the origin of the term *electricity.*
2. What change took place (*a*) on the hard rubber, and (*b*) on the glass rod when it was electrified?
3. Discuss the theory of the production of lightning.
4. Explain the action of the electrical whirl.
5. Why is a pith ball first attracted to a charged piece of wax and then repelled?
6. Explain the action of the electroscope.
7. Give a short description of the static machine.
8. Name five conductors and five insulators.
9. What is the fundamental difference between an insulator and a conductor?
10. What is the value of a lightning rod?
11. List the requirements of a good lightning rod.
12. Describe two methods of producing static charges.
13. Why is static electricity most noticeable on dry days?
14. Explain the charges on bodies in terms of the electron theory.
15. Describe a simple condenser. For what is a condenser used?
16. How may it be shown that there are two kinds of electrification?
17. How may a positive charge be produced? Explain in terms of the electron theory.
18. State the facts of static electricity and explain each fact.
19. State the laws of static electricity.
20. Describe Franklin's kite experiment. What did it prove?
21. Distinguish between magnetic and electric forces.
22. How may a body be charged permanently by induction?
23. Explain why the whole electric charge is on the surface of a conductor.
24. Suggest a method of charging an electroscope negatively.
25. Why do gasoline trucks have a chain drag along the ground?
26. What is meant by difference of potential? In what terms is it measured?
27. There are at least three ways in which lightning could injure a person standing under a large tree during a thunderstorm. Can you suggest what they are?
28. Can you suggest a reason why we should not go swimming during a thunderstorm?

UNIT VII

SECTION 3

AN ELECTRIC CURRENT USUALLY CONSISTS OF A STREAM OF ELECTRONS

Introduction.

A stream of electrons is known as an *electric current*, the nature of which forms the topic for this Section. It is true that an electric current is produced when electrons stream from one charged body to another through a conductor, but in so doing, the difference in potential, due to the difference in charge, is equalized. Maintenance of an electric current requires the renewal of the charge. Franklin could entertain his friends with a dinner at which he served a turkey killed by the discharge from a Leyden jar, but such a discharge will not light city streets, run electric trains, nor cook the turkey.

Galvani Discovered Electric Currents.

Luigi Galvani (1737–1789), an Italian professor of anatomy and obstetrics at the University of Bologna about 1768, noticed that the severed leg of a frog contracted under the influence of a nearby electrostatic machine. This observation aroused his curiosity, and he determined to see whether or not atmospheric electricity would have the same effect. Electricity, carried down a lightning rod specially erected for this experiment, produced the same twitching when a storm approached. He also found that this twitching was produced when a nerve and a muscle were connected with two dissimilar metals placed in contact with each other. Galvani concluded from this experiment that the source of the current was in the frog itself. How was he to know that these two metals in contact with the saline juices in the frog's leg constituted the world's first observed chemical electric cell? Galvani's work was of importance because it stimulated a great deal of investigation. For this service alone it is quite fitting that he be honored by having electric currents and instruments named after him respectively as "galvanic" currents and the "galvanoscope" and "galvanometer."

Volta Invented the First Successful Chemical Cell.

Alessandro Volta (1745–1827), professor of physics at the University of Paris, was another distinguished investigator of this period. Volta discovered that when two metals similar to those used by Galvani made contact between his mouth and his eye, he experienced the sensation of light. He noticed the formation of a bitter taste when a copper coin and a gold coin were placed on opposite sides of his tongue and connected with a wire. From these results he arrived at the conclusion that these effects were produced by the two metals. He showed that a frog's leg would twitch when touched with two wires heated unequally and thus laid the foundation for the thermocouple. In 1800 Volta invented the Voltaic pile, which consisted of a series of little disks of zinc, copper, and paper moistened with water or brine and placed upon each other in the order named. He also produced the "crown of cups," which consisted of a series of vessels filled with brine or dilute acid, each of which contained a strip of zinc and copper. Thus Volta provided the first source of continuous electric current, the chemical cell, which opened up a wide range of experiments by his contemporaries.

Any Combination of Metals and Electrolytes Constitutes an Electric Cell or Battery.

The science of electrochemistry started with Volta's electric pile. It was soon discovered that when two brass wires leading from a voltaic pile were placed near each other in water, there followed an evolution of hydrogen gas at one wire and an oxidation of the other wire. Platinum or gold wires did not oxidize but evolved oxygen gas. The proportion by volume of hydrogen and oxygen evolved was found to be two to one, or the same as the proportion of hydrogen and oxygen in water; hence, the water was said to be decomposed.

Later, other compounds were decomposed, and silver and copper were deposited from their solutions on one of the wires leading from the pile, thus paving the way for electroplating. Many other chemical changes were brought about, but further discussion of electrochemistry must be saved for the next Unit.

To produce an electric current, some form of energy must be converted into electrical energy in order to maintain the current. In this case the source of the current is chemical energy, and the stream of electrons flows between two metals when they are placed in a solution that conducts the electric current and are connected outside of the cell because one metal has a greater affinity for electrons than the other. One metal gives up electrons and, in the process, goes into

solution, while another metal in solution accepts electrons and goes out of solution. It is this chemical change that supplies the energy for the production of the electric current.

A simple electric cell consists of strips of copper and zinc immersed in sulfuric acid. These two strips of metal are called the *electrodes*, while the acid solution, or any other solution that will conduct the electric current, is called the *electrolyte*. It has been found that an electric current may be produced by any of the following combinations of electrodes and electrolytes provided that there is differential chemical action.

Electrode	*Electrolyte*
1. Any two metals	in one electrolyte
2. One metal	in two different electrolytes
3. One metal	in two different concentrations of the same electrolyte
4. Different concentrations of one metal	in one electrolyte

In every case there is a chemical reaction in which a stream of electrons is produced.

About twenty years after the invention of the voltaic cell, a discovery was made which led to the invention of another generator of electric current, the electric motor. Before we take up the discoveries which led to the electric motor, we must pause briefly to learn a little about the electric current.

An Electric Current Is Similar to a Flow of Water in a Pipe.

In order that water shall flow in a pipe, the pipe must be of sufficient size to carry the desired quantity of water, and there must be a pressure to maintain the flow of water. The pressure may be supplied by a tank filled with water at a higher level than the water outlet.

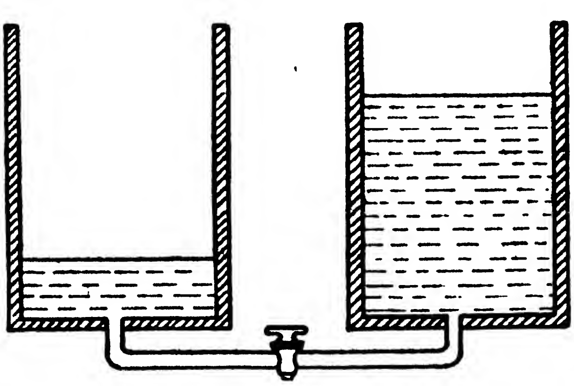


FIG. 235. The difference in water level is similar to the difference in electrical potential.

If the water outlet is opened, the water will run out of the tank, and the flow of water will stop. This corresponds to the discharge of an electrical charge through a conductor.

If the water level is maintained in the tank, then the water will continue to flow through the pipe at the same rate. This level may be maintained by a pump, which thus supplies the energy contained by the flowing water. Instead of a

difference in water levels, there is a difference in the electric circuit, called a *potential difference*, which is maintained by the electric battery or the generator which supplies the energy to maintain a steady flow of electrons through the wire.

The valve in the water pipe corresponds to the switch in the circuit.

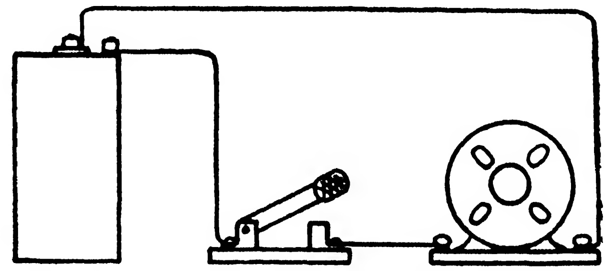


FIG. 236. The cell maintains a difference of potential and supplies the energy to operate a small motor when the switch is closed.

The requirements for an electric current are, therefore, a sustained difference of potential and a conductor.

Pipes offer resistance which cuts down the flow of water. Electrical conductors also offer resistance to flow. A small wire will not conduct so much current as a large wire for equal differences in potential, while many substances offer a high resistance to the flow of the current.

In making diagrams of electrical circuits, a cell is designated by a long and a short vertical line parallel to each other. A straight line represents a conductor, while a zigzag line represents a resistance.

The resistance of a circuit determines the amount of current that will flow under a given difference of potential. This is a simple statement of Ohm's law.

The electric current, the difference of potential, and the resistance may all be expressed in familiar units:

Current	Amperes .	(Ampère)
Resistance	Ohms . .	(Ohm)
Difference of potential .	Volts . .	(Volta)

Difference of potential is also called voltage. An instrument that measures voltage is a voltmeter. It corresponds to the pressure gauge on a water line. The ammeter is the instrument designed to measure amperes, or current, and corresponds to a water meter (flow-meter type) which measures the flow of water in gallons per unit of time. Water meters, which measure the total amount of water flowing, correspond to coulometers, which measure coulombs. The unit of electric current, the ampere, corresponds to the flow of one coulomb per second. A coulomb per second corresponds to the flow of 6.30×10^{18} (6,300,000,000,000,000,000) electrons per second. It is the amount of current that will cause the deposition of 0.001118 gram of silver from a solution of silver nitrate in one second. The unit of resistance, the ohm, is the resistance offered by a conductor which conducts one ampere under a potential difference of one volt.

Ohm's law may now be stated as follows:

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

or

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$

or, using accepted abbreviations,

$$\text{I (Current)} = \frac{\text{E (Electromotive force)}}{\text{R (Resistance)}}$$

The electromotive force is the maximum potential difference of a cell, that is, the potential difference that exists when no current is being drawn from the cell. The resistance in this formula refers to the total resistance in a circuit, both internal and external.

Electrical Power Is Measured in Kilowatt-hours.

Electric power is paid for in terms of watt-hours rather than volts or amperes. The watt is equal to the product of the voltage times the number of amperes, just as

$$\text{Fluid power} = \text{Pressure} \times \frac{\text{Volume}}{\text{Seconds}}$$

in proper units,

$$\text{Volts} \times \text{Amperes} = \text{Watts}$$

The kilowatt-hour, the most common electrical-energy unit, is the energy delivered in an hour at the constant rate of one kilowatt.

Everyone should be able to make simple calculations which will enable him to determine the relative cost of operation of his various electrical appliances. Supposing that electrical current costs five cents per kilowatt-hour, what would it cost to operate the following appliances for one hour?

Appliance	Wattage Found on Label on Appliance	Cost of Operation in Cents per Hour
Radio	100	0.50
Light	50	0.25
Clock	2	0.01
Toaster	600	3.00
Hot-water heater	3000	15.00
Stove — 1 unit	1000	5.00
Iron	600	3.00
Washing machine	594	2.97

The label on the washing machine did not list the wattage, but it did list the amperes as 5.4. Since the voltage in this case was 110, the wattage was calculated as follows:

$$\begin{array}{llll} \text{Volts} & \times \text{ Amperes} & = & \text{Watts} \\ 110 & \times \quad 5.4 & = & 594 \end{array}$$

It should be noted, however, that motors are not usually worked to full power.

A few such calculations would enable the home-owner to determine what his money is paying for when he pays his electric bill and to tell where to institute economies intelligently.

It will be noted that the most power is consumed by household appliances which transform electricity into heat. Heat is produced when an electric current is forced through a resistance. Electric heating devices are usually wound with alloys of nickel and chromium, which offer electrical resistance and at the same time resist destruction by chemical reaction at high temperatures. Most heating elements burn out eventually, *i.e.*, the wires gradually become oxidized by high temperatures or evaporate if in a vacuum.

The heat produced by passing a current through a resistance can be demonstrated by short-circuiting a fully charged automobile battery (if you do not care what happens to the battery) with a large iron nail which will become red hot in a very short time.

The resistance of metals becomes greater as the temperature rises, because, according to one theory, it becomes increasingly difficult for the electrons to pass through the metal as the agitation of the molecules increases. The electrical-resistance thermometer consists of a coil of wire in a quartz shield which has a very high melting-point. The thermometer may be placed in a furnace and the temperature determined by measuring the increase in its electrical resistance.

There Are Two Kinds of Current Electricity Which May Be Run to Appliances through Conductors in Series or Parallel.

There are two kinds of current, direct and alternating. Direct current consists of a stream of electrons moving in one direction only and is produced by chemical cells and certain types of generators.

Alternating current, produced only by certain types of generators, consists of a stream of electrons which reverses its direction in the conductor many times per second.

Two or more conductors may be connected in series or parallel, as shown in Figs. 237 and 238.

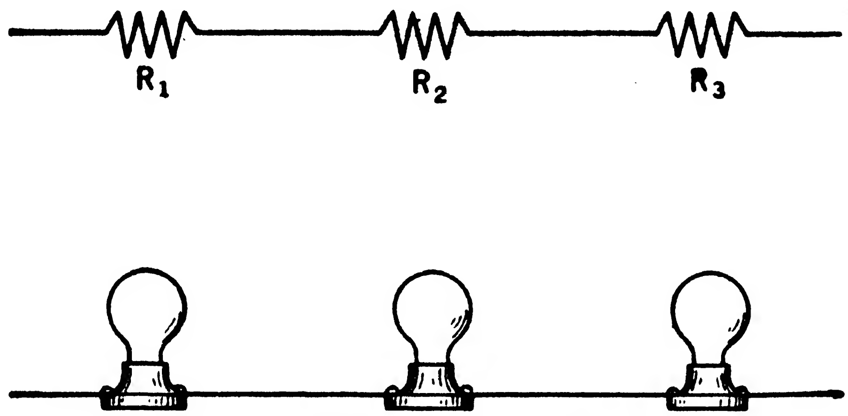


FIG. 237. Series wiring.

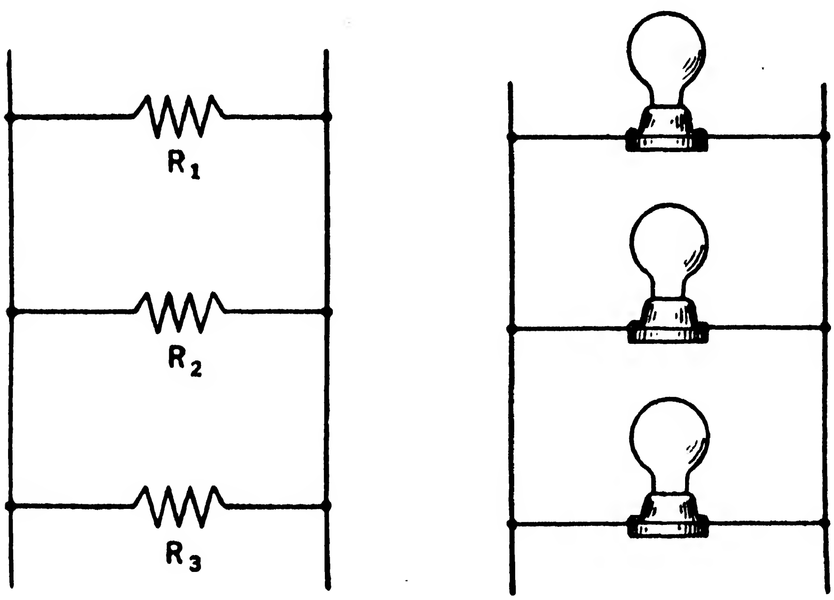


FIG. 238. Parallel wiring.

The combined resistance of all conductors is equal to the sum of the resistances of each conductor in a series, while the effective resistance to the flow of current by the same number of conductors in parallel is less than that offered by any one conductor. This is shown by the water analogy.

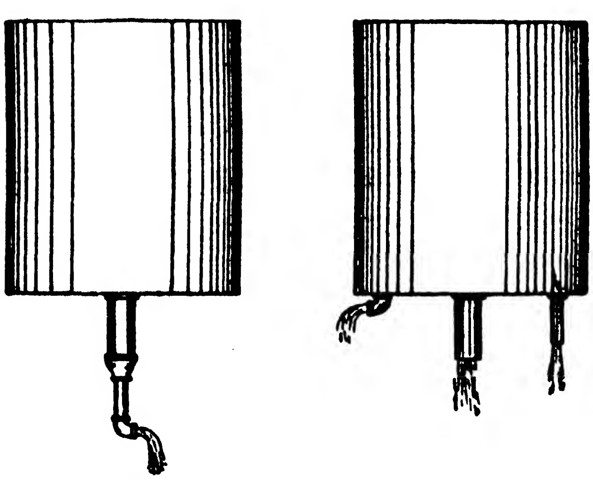


FIG. 239. The resistance to the flow of water is greater when the three sections of pipe are connected in series than when connected in parallel.

Christmas-tree lights are often strung together in series. If the current of an ordinary house-lighting circuit passes through one of these lights, it will be burned out at once because it was designed to carry much less current. This would not have been so had the current passed through all of the lights in the string because less current flows as a result of their combined resist-

ance. In such a string all the lights go out when one light goes out because the flow of current is broken at this point.

Lights in ordinary house-lighting circuits are wired in parallel, thus enabling one light to be turned off without affecting the others. If such lights were wired in series, the light in each bulb would grow dimmer for each added bulb, because the added resistance would decrease the amount of current flowing.

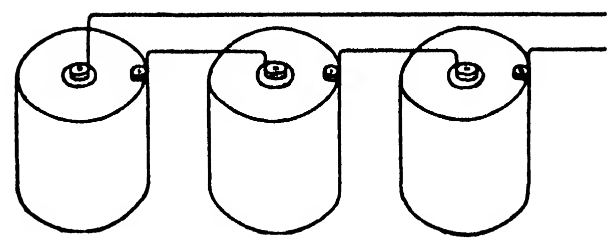


FIG. 240. Cells are usually connected in series.

Cells are generally connected in series; the voltage of the series is equal to the sum of the voltages of each of the individual cells.

STUDY QUESTIONS

1. What is the nature of an electric current?
2. Differentiate between direct and alternating current.
3. Use the water analogy in explaining the flow of an electric current through a conductor.
4. Describe the original observations that led to the first chemical cell.
5. List the different combinations of metals and electrolytes that will produce an electric current.
6. State Ohm's law. Give an application of this law.
7. Name the electrical unit of measurement for each term in Ohm's law.
8. In what units is electrical power sold? What is the meaning of these units?
9. Differentiate between series and parallel wiring. When is series wiring desirable?
10. How much would it cost to operate an electric iron that uses 6 amperes of an ordinary 110-volt current for 24 hours if the electrical power sells for 6 cents a kilowatt-hour?
11. What is the resistance of a 110-volt electric toaster that has a rating of 600 watts? How much would it cost to operate the toaster for 3 hours if the power costs 12 cents a kilowatt-hour? How long could a 50-watt lamp be operated for the same amount?
12. Is resistance a property of electricity or of a conductor?
13. Explain how one can connect several conductors so that their combined resistance will be less than the sum of their individual resistances.
14. What type of electrical household appliances cost the most to operate?
15. Give the main facts of current electricity.
16. Give the laws of current electricity.
17. Give the theory that explains the laws and facts of current electricity.
18. Try to apply Ohm's law to some other type of energy.
19. Why is it that electricity will not flow to an object but has to flow through the object if the current is to flow at all?

UNIT VII

SECTION 4

THE DISCOVERY OF ELECTROMAGNETISM LINKED MAGNETISM AND ELECTRICITY

Behind all your practical applications, there is a region of intellectual action to which practical men have rarely contributed, but from which they draw all their supplies. Cut them off from this region, and they become eventually helpless. — John Tyndall.

Introduction.

Two discoveries of fundamental importance in putting electricity to work were made in the nineteenth century. The first discovery, made in 1820, that of *H. C. Oersted*, a Danish physicist, was that an electric current produces a magnetic field in its vicinity. The second discovery, in 1831, was made by *Michael Faraday*, who found that under certain conditions a magnetic field can be made to produce an electric current. These two discoveries laid the foundations for the harnessing of electrical energy. In this Section the general characteristics and applications of electromagnetism will be studied, reserving Faraday's discovery and its applications for the next Section.

Oersted Discovered That an Electric Current Produces a Magnetic Field.

Once the chemical cell had been invented, thus furnishing a convenient source of current electricity, investigators began to study the possible relationship between electricity and magnetism. Oersted had been trying to find out whether there was any effect when a wire carrying a current was held above a compass at right angles to it. No effect was noted. According to one story, he accidentally placed the wire parallel to the needle during the course of a lecture and was much surprised to see the needle turn aside. Oersted then tried placing the wire below the needle, and the needle was deflected in the opposite direction.

A. M. Ampère, a French investigator, after whom the unit of electric current was named, worked out the principle of this relationship between the electric current and the magnetic field and suggested that

it could be used in communication. By sending an electric current through a wire, a compass needle can be deflected and can thus be made to transmit messages. The first electromagnetic telegraph was built in Göttingen in 1833 by *Karl Friedrich Gauss* and *Wilhelm Weber*.

Another characteristic of Oersted's discovery was that no practical applications seemed likely at the time his work was published. Lord Kelvin said concerning this:

> Oersted would never have made his great discovery of the action of galvanic currents on magnets had he stopped in his researches to consider in which manner they could possibly be turned to practical account; and so we should not now be able to boast of the wonders done by the electric telegraphs. Indeed, no great law in Natural Philosophy has ever been discovered for its practical application, but the instances are innumerable of investigations apparently quite useless in this narrow sense of the word which have led to the most valuable results.[1]

At the same time, it should be pointed out that though Oersted was not seeking an immediately practical application, nevertheless he and his contemporaries knew that practical applications could be expected from the kind of knowledge he and others were gleaning.

A Magnetic Field Encircles a Wire Which Is Carrying an Electric Current.

It is now known that when an electric current flows through a straight wire a magnetic field is set up encircling the wire at all points. The direction of this field can be determined with a compass, which shows that the magnetic field is at right angles to the direction of flow of the current. When the direction of flow of the current is reversed, the direction of the magnetic field is reversed. The strength of the magnetic field surrounding a wire carrying a current is proportional to the amount of current being carried.

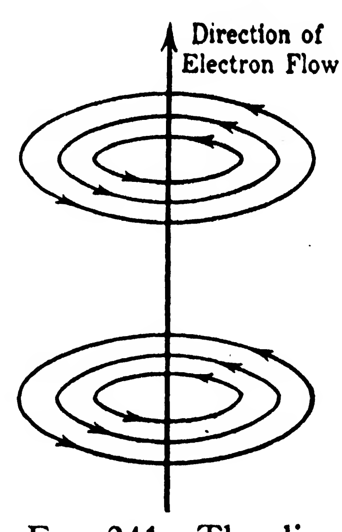


FIG. 241. The direction of lines of force of the magnetic field encircling a wire carrying an electric current.

The magnetic field surrounding a wire can be nicely demonstrated by placing iron filings on a card through which a wire carrying a current passes. Upon tapping the card, the filings will line themselves up in such a way as to show the direction of the lines of force.

[1] Sir Richard Gregory, *Discovery, the Spirit and Service of Science*, The Macmillan Co., New York, 1929, p. 241. By permission.

A Coil of Wire Carrying an Electric Current Behaves Like a Bar Magnet.

When a wire carrying a current is bent into the shape of a loop, all the lines of force outside the loop are pointing in one direction, and the same is true of those inside the loop. There is thus a strong mag-

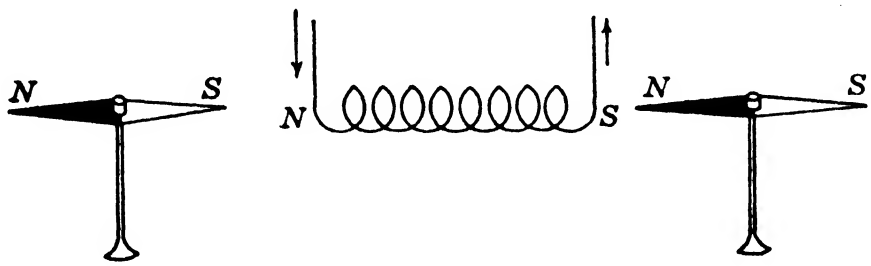


FIG. 242. A coil of wire conducting an electric current behaves like a bar magnet as shown by the compass needles.

netic field within the loop. If many loops or turns are added, the magnetic field becomes still stronger. Such a coil of wire carrying a current behaves like a bar magnet.

The magnetic field through a coil of wire can be very greatly strengthened by placing a core of soft iron in the center. Because of its high permeability to the magnetic lines of force, a great number of lines of force pass through the iron core and make of it a powerful magnet. Such an *electromagnet*, as it is called, acts as a permanent magnet, but only so long as the current is flowing through the coil; its polarity depends on the direction of flow of the current. The strength of the electromagnet is proportional to the amount of current flowing through the wire and also to the number of turns in the coil. Electromagnets have many applications; doorbells, telegraph sounders, magnetic brakes, sensitive relays, lifting magnets, and many other devices are operated by electromagnets.

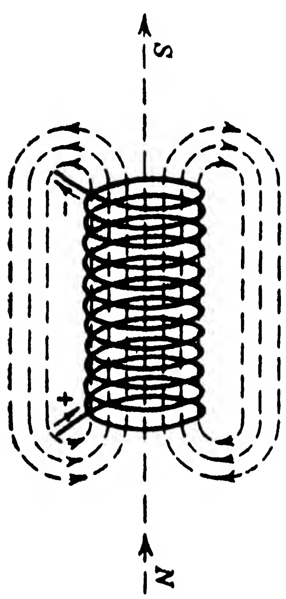


FIG. 243. The magnetic field of a helix.

A coil of wire carrying an electric current is called a *solenoid*. Solenoids are used in industry to operate many automatic devices. If a coil of wire is placed in a vertical position, an iron core, which is held within the coil by the magnetic field as long as the coil is carrying an electric current, will drop through the coil when the circuit is broken. Such a device can be used to lock and unlock doors.

The ordinary electric doorbell consists of a clapper which strikes the bell when the iron strip to which it is attached is attracted to an electromagnet. A spring draws the iron piece back when the current

is broken. The vibratory motion of the clapper is produced by an ingenious make-and-break device that breaks the circuit when the iron strip is drawn to the magnet and closes the circuit when the strip is drawn back by the spring.

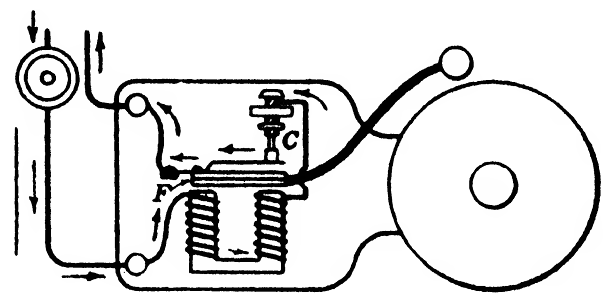


FIG. 244. An electric bell.

Morse Invented the Telegraph.

In 1832 *Samuel Morse* (1791–1872), an artist, fell into a conversation with Dr. Jackson, a fellow-passenger on the ship in which he was returning to America from Europe. During this conversation, which had turned to the wonders of the recently perfected electromagnet, Morse conceived the idea of sending signals by means of an electric current. He gave up his profession as an artist and, after five years, patented his *telegraph*. After seven more years of patient, persistent work amidst poverty and discouragement, the commercial importance of the telegraph was demonstrated when he was able to send the famous message, "What hath God wrought?" from Washington, D. C., to Baltimore.

The earliest form of the telegraph consisted of a key at one end of the telegraph wire for opening and closing the electric circuit and an electromagnet at the other end. When the sending key was closed, the current passed through the electromagnet and caused it to attract a piece of soft iron to its core. When the current stopped, the iron was pulled away from the core by means of a spring. A code of dots and dashes was used in sending messages. The first telegraph instruments recorded the signals on a tape, but later the message was read by the operator directly from the sounds of the bar as it clicked against the electromagnet.

The distance of the early telegraph lines was limited because the current was decreased so much by the resistance of the wire and other losses that it was too weak to operate the electromagnet. This difficulty was overcome by the use of relays at suitable distances to increase the current. These relays were simply devices to close the switch in the "next" circuit and thus carry the signal along the line from circuit to circuit.

By 1872, when Morse died a rich and famous man, there had been many improvements over his original telegraph system, and many additional improvements have been made from year to year up to the present time. Modern telegraph systems use clever devices by which messages may be sent over a wire in both directions at the same time;

and today the capacity of a telegraph system has been increased still more by sending a number of messages over a single pair of wires at the same time. In actual practice eight messages are usually sent simultaneously, but more may be added if desired. Automatic typewriters, operated directly by the telegraph signals and based on the use of a group of electromagnets, form the basis of the modern teletype used in newspaper and police work. One linotype machine could operate all the other linotype machines in the United States by means of the telegraph.

Lord Kelvin Perfected the Transatlantic Cable.

When *Lord Kelvin* (1824–1907), then named *William Thomson,* finished his work at Cambridge, one of his examiners remarked to another, "You and I are just about fit to mend his pens." Lord Kelvin was one of those rare men, like *James Watt,* in whom there was a combination of mechanical ingenuity and scientific genius. There is no question as to the value of practical application as an incentive to scientific work. Some of the world's greatest scientists, like *Louis Pasteur,* have been spurred on to greater endeavors by the supreme desire to help solve some of the pressing problems of humanity. Lord Kelvin expressed this idea as follows:

> The life and soul of science is its practical application; and just as the great advances in mathematics have been made through the desire of discovering the solution of problems which were of a highly practical kind in mathematical science, so in physical science many of the greatest advances have been made in the earnest desire to turn the knowledge of the properties of matter to some purpose useful to mankind.

Not only did Kelvin make contributions to the science of thermodynamics and other theoretical studies, but also did he earn the profound gratitude of all navigators and those whose lives depended on the latter for his improvements of the compass and his introduction of the sounding line.

The first transatlantic submarine cable, laid in 1858, soon failed. Lord Kelvin designed a new type of strand cable better adapted to stand the strain of laying and repairing and invented the mirror galvanometer and siphon recorder for receiving the messages sent over the cables. Both instruments were applications of electromagnets, as are the majority of electrical measuring instruments. Lord Kelvin also designed electrical measuring instruments for almost every purpose.

In 1896 a tremendous celebration was held in honor of this great physicist, fertile inventor, and inspiring and beloved teacher. As part

of this celebration a message was sent from Glasgow to San Francisco and returned by a different route, a total distance of 20,000 miles, in only seven minutes. What a tremendous development in communication took place in the lifetime of Kelvin! At the time of his death there were over 225,000 miles of cables in use in the world.

Electrical Measuring Instruments Employ the Electromagnet.

The galvanometer consists of an electromagnet which is moved under the influence of a field of a permanent horseshoe magnet when the current passes through the coil. The coil is attached to the pointer, which moves over the scale of the instrument. Of course, the coil could be fixed in position and the permanent magnet moved, and some instruments are made that way. The relative motion of the coil and magnet is the result of the repulsion of like magnetic poles for each other.

A very sensitive galvanometer is employed in the electrocardiograph to study the character of the heart-beat. It is activated by a minute electric current generated each time the heart muscles contract. Galvanometers indicate a flow of current, but they may be so designed and connected in a circuit as to measure either amperes or volts, in which case they are called ammeters or voltmeters.

Some important applications of electromagnetism used in generators, motors, and transformers will be studied in the next Section.

Defective Railway Rails Are Located by the Sperry Detector.

The Detector Car, invented by *Elmer A. Sperry*, made its first commercial test on a railwoad in 1928. During the twelve years from 1928 through 1940, over 651,000 miles were tested by this device, and 345,000 defective rails were located and replaced, thus preventing an untold number of accidents in these days of higher train speeds and heavier axle loads. The Sperry Detector generates a current that passes through the rails over which it rolls. The electromagnetic field changes as the current encounters a fissure and causes a "paint gun" to squirt white paint on the defective rail.

STUDY QUESTIONS

1. To whom do accidental discoveries usually come?
2. How are electromagnets used today?
3. Name two discoveries of fundamental importance in putting electricity to work. Who made these discoveries?
4. How would you construct an electromagnet?
5. How may the polarity of an electromagnet be reversed?
6. Give the principle of the first telegraph system.

7. What is the principle of galvanometers and other electrical measuring instruments?
8. Should scientists be concerned about the practical importance of their researches?
9. What contributions did Lord Kelvin make to the field of electricity?
10. If you face the direction of flow of an electric current through a wire, will the direction of the magnetic lines of force be clockwise or counterclockwise?
11. Which hand should you place around a wire so that the finger will point in the direction of the magnetic field when the thumb points in the direction of electron flow?
12. Diagram the magnetic field surrounding a trolley wire. Have you ever observed the effect of such a magnetic field on an automobile radio? Do power lines show similar magnetic fields? Why do telephone lines have much weaker magnetic fields?
13. Explain the action of the electric doorbell.
14. Who discovered the principle of electromagnetism?
15. Who invented the telegraph based on the use of electromagnets?
16. Describe a telegraph system based on the use of a compass instead of an electromagnet.
17. Upon what three factors does the strength of an electromagnet depend?

UNIT VII

SECTION 5

ELECTROMAGNETIC INDUCTION MADE POSSIBLE THE PRACTICAL GENERATION, TRANSMISSION, AND UTILIZATION OF CURRENT ELECTRICITY

The philosopher should be a man willing to listen to every suggestion, but determined to judge for himself. He should not be biased by appearance; have no favorite hypothesis; be of no school; and in doctrine have no master. He should not be a respecter of persons but of things. Truth should be his primary object. If to these qualities be added industry, he may indeed hope to walk within the veil of the temple of nature. — Faraday.

Introduction.

Michael Faraday (1791–1867) was the first man to visualize and name the magnetic lines of force. His studies led him to wonder why magnetism should not produce electricity, inasmuch as electricity

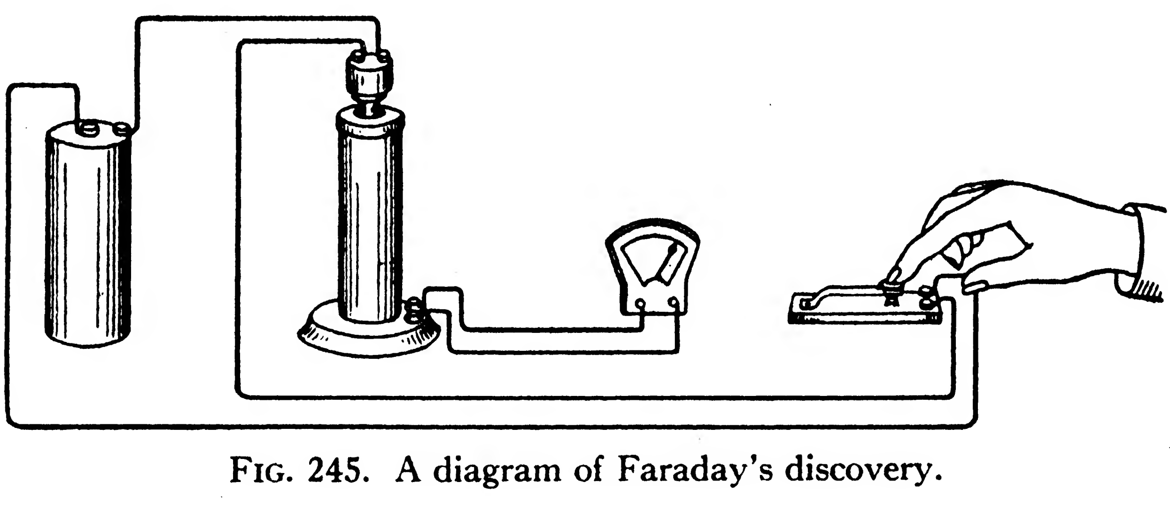


FIG. 245. A diagram of Faraday's discovery.

produces magnetism. The induction of electrical charges by other static charges of electricity suggested the possibility of inducing a current of electricity by use of the current from chemical cells. Faraday wound two coils of insulated wire on the same iron ring and passed a steady current through one coil, while he observed that no deflection was produced in a galvanometer attached to the other coil. He observed, however, that a slight deflection of the galvanometer occurred when the current was started or stopped. This observation was

the first of many which he made to show that an electromotive force is produced, resulting in an electric current in a closed circuit, when a conductor is moved through a magnetic field.

Electromotive Forces Resulting in Electric Current May Be Induced by Moving a Coil of Wire through a Magnetic Field.

An electromotive force is produced, resulting in an electric current, by causing a conductor to move through a magnetic field. It makes no difference whether the source of the magnetic field is a permanent magnet or an electromagnet. The same effect may be produced by moving the magnetic field so that the conductor cuts the lines of force.

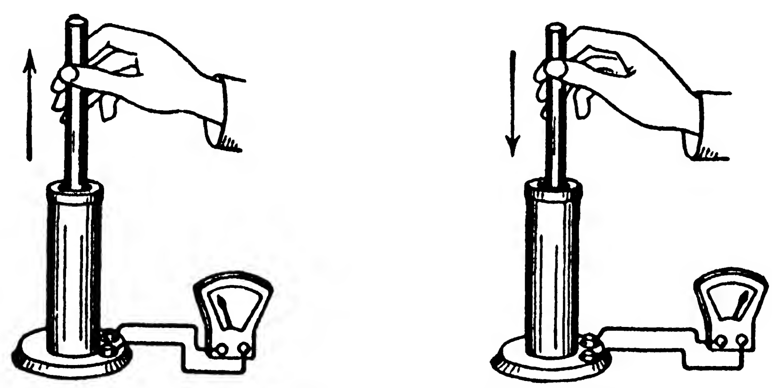


FIG. 246. The galvanometer shows that a current of electricity is produced when the magnet is moved up or down within the coil.

The current flows only during the motion. The strength of the electromotive force, *i.e.*, the voltage, depends upon the number of lines of force cut per second and upon the number of turns in the coil which is cutting the lines of force, while the amount of current flowing, *i.e.*, the amperage, depends upon the strength of the magnetic field.

A coil of wire called an "earth inductor" may be moved through the earth's lines of force and thus produce an electromotive force resulting in an electric current if rotated about an axis properly directed in its relation to the earth's lines of force.

Induction Coils Have Many Uses.

An induction coil is used to increase the electromotive force (voltage). It consists of two coils, one called the "primary," having only a few turns, while the other, the "secondary," has many turns. Every additional turn in the coil increases the voltage proportionately because the lines of force are cut once for each turn. Because the voltage of the induced current depends upon the relative number of turns of wire in the secondary and primary, a considerable increase in voltage can be obtained with an induction coil. In order to induce a current in the secondary, a method must be found to move the electromagnetic field.

This may be accomplished by use of an automatic interrupter, which makes and breaks the current several times a second.

The induction coil consists of a strong electromagnet, made up of a core surrounded by the primary coil, and a secondary coil usually wrapped around the primary coil. Induction coils are capable of building up such high voltages that sparks may be made to jump several inches through the air. The distance a spark will jump through the air depends upon the dryness of the air, the shape of the conductors, the form of gap terminals, and other factors. In ordinary air an electromotive force of ten to thirty thousand volts is needed to make a spark jump across one centimeter. One can easily calculate the voltage required to make a spark jump several inches, using information given in a previous section. Induction coils are used where high voltage and low amperage are needed, as in furnishing a spark for igniting gases in internal-combustion engines or in operating X-ray tubes.

The Tesla coil is a type of induction coil, designed by an American electrician, *Nicola Tesla*, for the production of very high voltage. It depends on the use of a very rapidly oscillating current in a coil, which greatly increases the rate at which the magnetic field changes. This oscillating current, sometimes oscillating with a frequency of a million times a second, is produced by the alternate charging and discharging of a condenser. An induction coil is used to charge the condenser. With the Tesla coil many spectacular experiments can be carried out. Although the voltage is very high and produces vivid flamelike discharges, it is quite harmless. One is not hurt by touching one of the terminals, because the current generated is very small and can do no harm because of the rapidity of the oscillations, and because the currents do not penetrate to vital organs.

Transformers Are Induction Coils Operated by Alternating Currents.

Induction coils require interrupters inasmuch as they use the direct current. Transformers are induction coils used to change the voltage when employing alternating current. Inasmuch as the direction of the alternating current changes many times per second, no interrupters are required in transformers. For many purposes direct current is required, but alternating current can frequently be used and has supplanted the direct type in most communities because electric power can be transmitted more economically by alternating current. The reason for this is that the voltage in the case of an alternating current can be raised by a transformer to a point where the loss in transmission due to resistance is reduced to a minimum; the high voltage can be lowered by another transformer at the place where the current is to be

used. Thus the transformer has permitted the commercial use of alternating current. A transformer which increases the voltage is called a *step-up* transformer.

Transformers in which the number of turns in the primary is greater than that in the secondary decrease the voltage and are called *step-down* transformers. In large transformers, the insulated coils are usually surrounded by oil to prevent short circuits and to keep the transformers cool. (The oil is cooled by radiators.) The coils in smaller transformers are frequently packed in pitch or tar for the same reason.

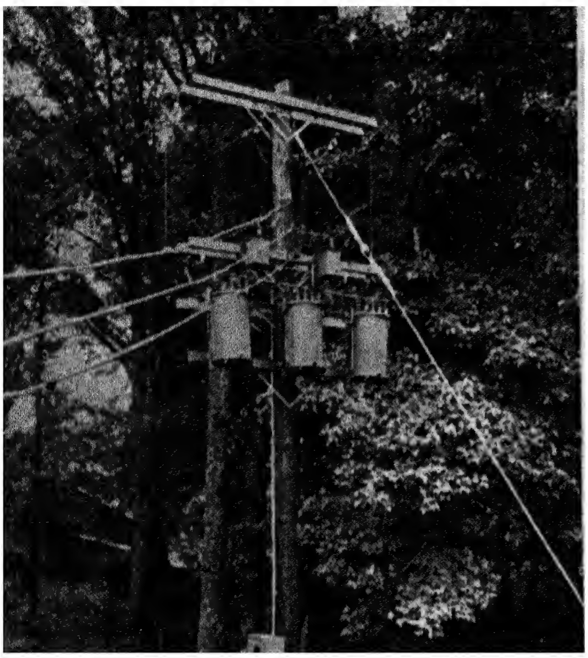


FIG. 247. Distribution transformers. (Courtesy of the Allis-Chalmers Manufacturing Company.)

In distributing current through a city, it has been found most economical and safe to transmit the power at 2000 to 4000 volts. Substations are generally located outside the city to transform higher voltages to the above voltages. Transformers are also located at points where this current is distributed to business houses or groups of dwellings to transform the voltage down to 220 or 110 volts. High voltage is dangerous, but the ordinary household current of 110 volts is not so hazardous, except when unusually good contacts are made, such as when one stands on a wet floor or in a bathtub and touches a poorly insulated electric appliance. Small transformers used for doorbells or toy railroads step down the voltage again to 6 or 8 volts.

Transformers which have just one turn in the secondary, using a wire of large diameter, produce a current of high amperage but low voltage. Such a current is used in electric welding because it enables sufficient heat to be obtained at the point of contact of two metals which form part of the circuit to weld them together; the heat is proportional to the product of the square of the current times the resistance.

A Choke Coil Acts by Self-inductance.

A choke coil, such as is used in radios or fluorescent light controls, consists of a coil of wire through which the current flows. The current sets up magnetic lines of force that cut the turns of wire in the coil and thus induce a voltage within the circuit that opposes the original volt-

age. This induced voltage is said to be self-induced. The induced electromotive force thus acts to *choke*, *i.e.*, prevent the current from rising rapidly to its final value, and it also prevents the current from stopping immediately when the electromotive force is removed from the circuit.

The Telephone Is an Application of Electromagnetic Induction.

The telephone was invented by *Alexander Graham Bell* (1847–1922) in 1876. Bell's first telephone was a crude device, in which the receiver and transmitter were essentially the same. The diaphragm was made of goldbeater's skin, an animal membrane which was attached to a permanent bar magnet by a kind of lever. This magnet was surrounded

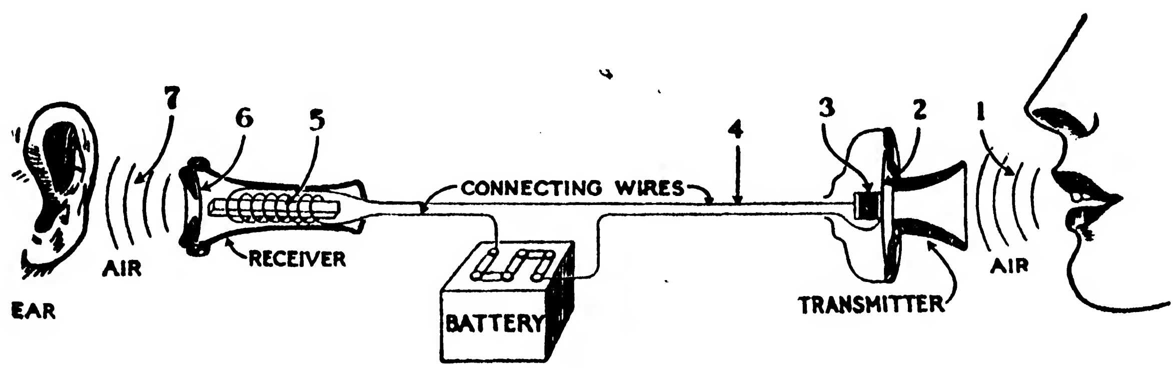


FIG. 248. The simplest telephone circuit. (Courtesy of the American Telephone and Telegraph Company.)

by a coil of wire, in which a current was induced when the magnet was moved by the vibrations of the diaphragm. In a later telephone, in which the transmitter and receiver were the same, a horseshoe magnet in the transmitter had two coils wound on its ends, from which wires were connected to similar coils in the receiver. A battery maintained the flow of current through the coils. Sounds caused the iron diaphragm in front of the magnet in the transmitter to vibrate. This caused a fluctuation in the current flowing through the coils, which was transferred to the diaphragm at the receiver end.

Since 1877 there have been more than ninety types of transmitters and more than sixty types of receivers designed and used. In 1877 *Thomas Edison* patented the carbon transmitter, which was so arranged that vibrations in the diaphragm produced fluctuations in the current. Behind the mouthpiece of the transmitter is a metal box containing two insulated disks between which are packed fine carbon granules. The current passes through these granules and varies with the changes in pressure on the carbon resulting from motion of the diaphragm. Thus the current passing through the wire is not induced as in the earlier type of transmitter but is modulated in intensity.

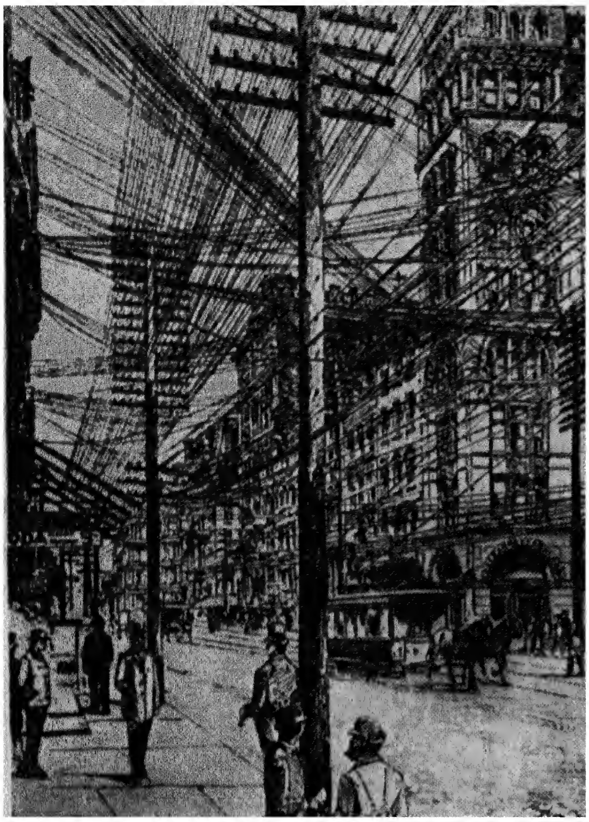


FIG. 249. Broadway and John Street, New York City in 1890. (Courtesy of the American Telegraph and Telephone Company.)

The telephone receiver contains a permanent horseshoe magnet with coils about each pole, through which the incoming current passes, causing the magnetic field of the magnet to fluctuate and thus altering its pull upon a thin sheet, or diaphragm, of iron near by. The resulting oscillation of the diaphragm transmits vibrations to the air outside, and in this way produces sound.

In the United States today the telephone messages sent out are twice the number of letters and postcard messages, the total number of messages exceeding 30,000,000,000 annually. The 20,000,000 telephones in the United States today represent approximately 60 per cent of the telephones of the world. In 1939 New York City alone had more telephones than France, Spain, Russia, Japan, or Sweden.

It is of interest to note that *Elisha Gray* invented the telephone at nearly the same time that Bell did but that Bell was granted the patent. However, Gray improved the telephone and founded the Western Electric Manufacturing Company, which at the present time manufactures most of the equipment used in the telephone industry.

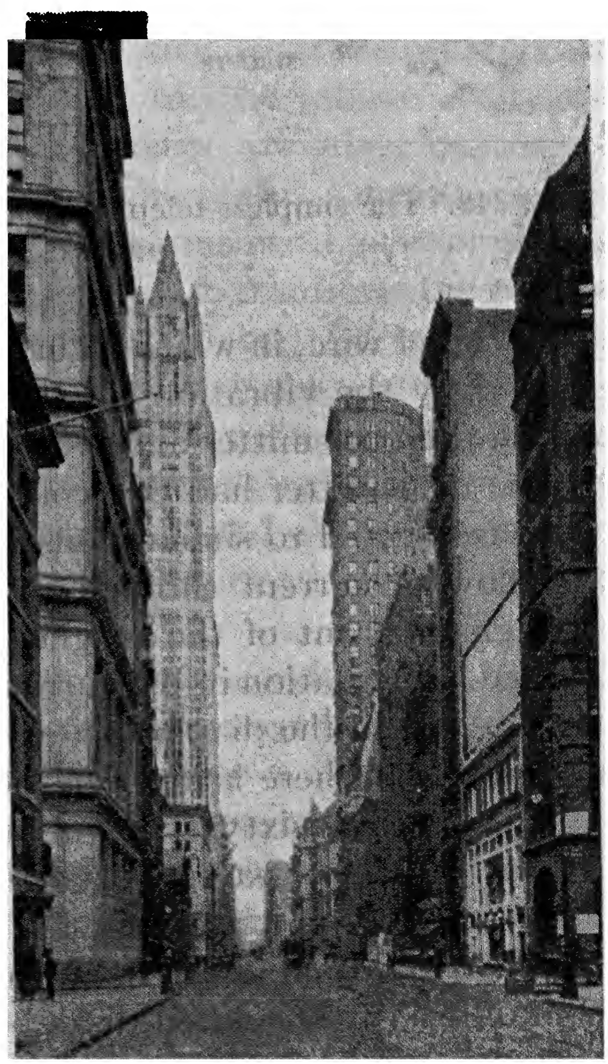


FIG. 250. Broadway and John Street, New York City in 1920. (Courtesy of the American Telegraph and Telephone Company.)

Faraday Devised the First Electric Generator.

Soon after his discovery of electromagnetic induction, in 1831, Faraday devised the first electric generator. In this experiment he rotated a coil of wire between the poles of a permanent horseshoe magnet and obtained a current from the coil. Nearly fifty years elapsed before this discovery was used with commercial success in the construction of the dynamo.

The Magneto Is a Simple Dynamo.

Magnetos are devices arranged so as to move a coil of wire through a field between permanent horseshoe magnets. They are called "magnetos" because permanent magnets are employed. The simplest generator is a magneto in which the loop of wire is attached to a shaft provided with two collars, to each of which one end of the loop is attached. Electricity is taken from these collars, as they revolve with the shaft, by means of carbon or copper contacts, called brushes. Little work is required to turn a magneto when the terminals of the moving coil are not connected by a switch through a lamp resistance; but when the switch is closed, it becomes difficult to turn the magneto. This resistance to motion results from the fact that the current produced in the coil sets up a magnetic field of its own which opposes the motion.

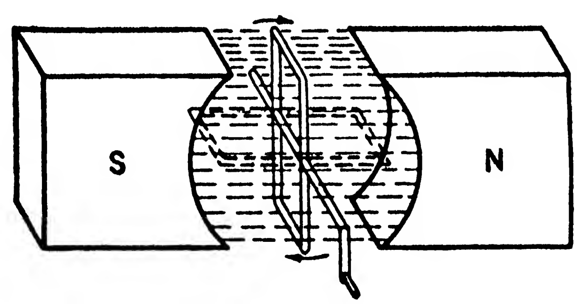


FIG. 251. Principle of a generator. A wire loop or coil cuts the lines of force between the poles N and S of a magnet.

The current produced by a magneto is an alternating current; that is, the current in the coil twice reverses its direction in each revolution.

Figure 251 shows why the magneto gives an alternating current. In the vertical position no lines of force will be cut, while in the horizontal position the maximum number of lines of force will be cut. Thus the current starts from zero, increases to a maximum, and again falls to zero for each half-turn. As the loop passes from one half-turn to the next, it cuts the field in an opposite direction and thus causes the direction of the current to be reversed.

The old style of telephone, in which the user turned a crank in order to ring a bell, depended upon the magneto. Magnetos may also be used, where electricity is not otherwise available, for furnishing the spark to ignite gaseous mixtures or a charge of powder in blasting operations. Many of the earlier automobiles used magnetos to furnish the spark to ignite the explosive gases in the cylinders and to light the

headlights. Such automobiles had to be started by cranking, for there was no spark until the magneto was turned as the automobile was cranked. The introduction of the storage battery and the induction coil permitted the use of the self-starter and electric lights.

Alternating-current Generators Are the Type Most Widely Used for Large Installations Today.[1]

If powerful electromagnets are used to replace the permanent magnet of a magneto, a greater electromotive force is generated, thus producing a larger current. The strength of the current may be further increased by greatly increasing the number of magnetic lines of force (by use of four, six, or even more electromagnets), by increasing the number of turns in the loop of wire, or by increasing the strength of the electromagnetic field.

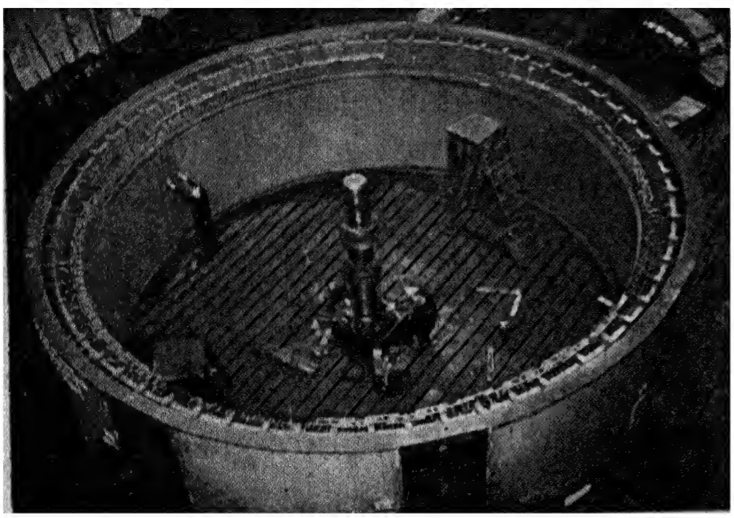


FIG. 252. Completing the stator for one of the generators at the Grand Coulee Dam. (Courtesy of the Westinghouse Electric and Manufacturing Company.)

Inasmuch as the direct-current generator produces direct current, a portion or all of this current, depending on the type of generator, may be used to excite the electromagnets. Direct-current generators differ from alternating-current generators in that they have commutators and do not need auxiliary exciting motors. Alternating-current generators require auxiliary direct-current motors to maintain a constant electromagnetic field. The rotor and stator of an alternating-current generator correspond to the armature and field of the direct-current generator.

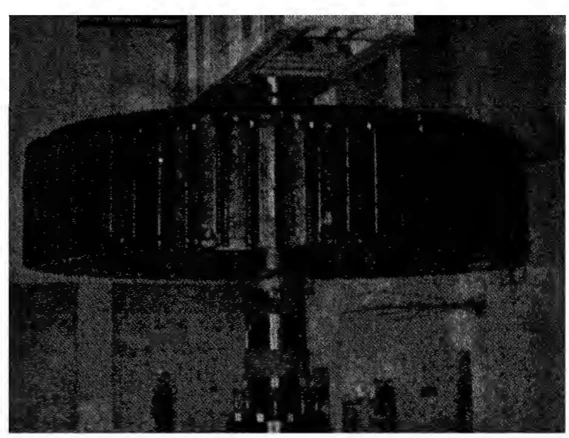


FIG. 253. The 527-ton rotor for one of the 108,000-kw. generators at the Grand Coulee Dam. (Courtesy of the Westinghouse Electric and Manufacturing Company.)

If direct current is desired from a generator, the collars or slip rings are split, forming a commutator,

[1] Automobile generators are the direct-current type.

so that, when the current reverses in the coil, the connections to the external circuit are also reversed.

The strength of the electromotive force, and therefore the strength of the current, will also be increased by increasing the number of coils of wire to be rotated in the magnetic field and by increasing the speed of rotation, which increases the frequency, *i.e.*, cycles per second.

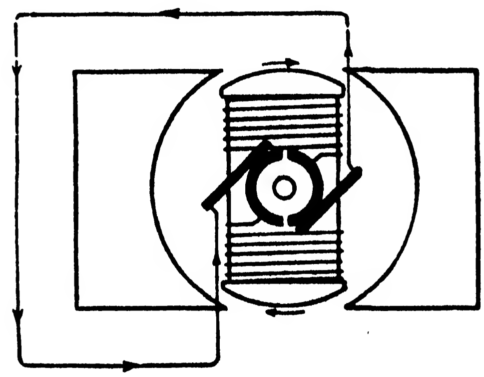


FIG. 254. The alternating current from the coil is automatically reversed by the commutator, thus changing it to a direct current.

The number of times the current reverses in direction depends upon the number of electromagnets in the stator and the speed with which the rotor rotates. Most alternators are built so as to give a current of 60 cycles (or 120 alternations) per second.

Motors Convert Electrical Energy into Mechanical Energy.

Faraday made the first very simple motor in 1821. The first commercial motors were made in the 1840's.

In 1873 a Belgian electrical engineer, *Z. T. Gramme*, was installing two electrical generators for the Vienna Industrial Exposition when a workman accidentally connected the wires from one generator that was in operation to the other generator that had not yet been installed. At once it began to rotate. So by accident it was discovered that a direct-current generator will run as a motor when supplied with a direct current at the proper voltage.

Any direct-current generator can be converted into a direct-current motor by supplying the generator with electric current through the brushes. The reason for this is that a mechanical force is exerted by a magnetic field on a conductor carrying a current. Whenever a conductor carrying a current is placed in a magnetic field in such a direction that the current flows at right angles to the field, the conductor experiences a force at right angles to both the direction of the current and the magnetic field.

Figure 255 shows a simple motor. In the motor the electricity passes through the coils of the rotor, causing the core to be magnetized. If this core is pointed in such a direction that the north and south poles are opposite the north and south poles of the permanent magnets, it will be repelled, because like poles repel each other. As it makes half a turn as a result of this repulsion, the direction of the current through the commutator is reversed, and the south pole becomes

the north pole, which is repelled again; thus the motor is kept running.

The armature (rotating loops of wire) is called the rotor, while the stationary electromagnets are spoken of as the stator, or field.

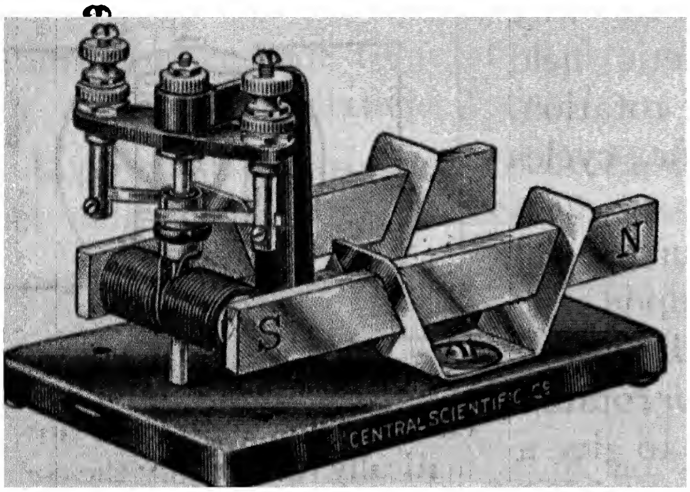


FIG. 255. A simple laboratory demonstration motor. (Courtesy of the Central Scientific Company.)

Motors are such compact machines that they can be directly attached to the machines which they are designed to operate, thus eliminating belts, shafts, or chains necessary to steam-driven machinery. Motors require little care and are ready to operate at any instant at the turn of a switch. By using motors of different sizes, no more than the minimum power necessary is used. The reader would find it a profitable exercise to compile a list of home appliances which utilize electric motors.

The average very small motor which is used in vacuum cleaners, sewing machines, stirrers, vibrators, and other household appliances will run on either direct or alternating current. Such motors are called "universal" motors. Two more efficient types of motors are known as the synchronous and induction alternating-current motors, most large alternating-current motors being of the latter type. The speed of synchronous motors depends upon the number of cycles per second of the alternating current supplied. Electric clocks are run by small synchronous motors, which are very simple in construction. The accuracy of electric clocks depends upon a continuous supply of current and proper regulation of the alternations in the current at the powerhouse. The fact that electric clocks are now in such wide use is an excellent testimony of the service furnished by most large electric-power companies.

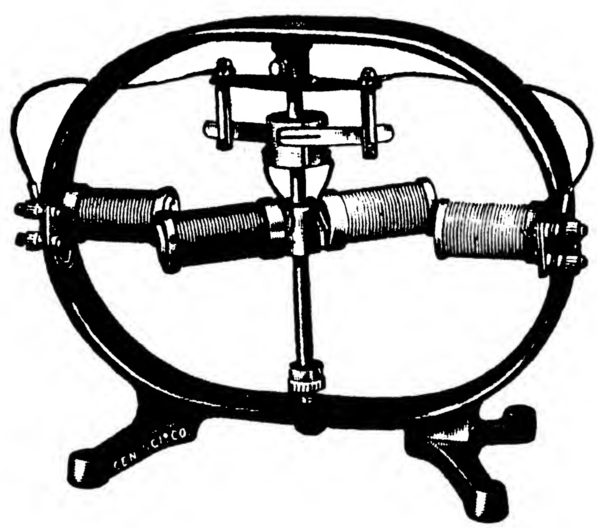


FIG. 256. A simple motor which uses electromagnets instead of permanent magnets. (Courtesy of the Central Scientific Company.)

Alternating Current May Be Changed to Direct Current by Several Methods.

A direct current may be generated by running a direct-current generator with an alternating-current motor. This is one of the best ways to produce direct current when only alternating current is available.

Several types of rectifiers, such as the tungar battery-charger, the kenotron radio tube, and the thyratron, or grid-glow tube, act as one-

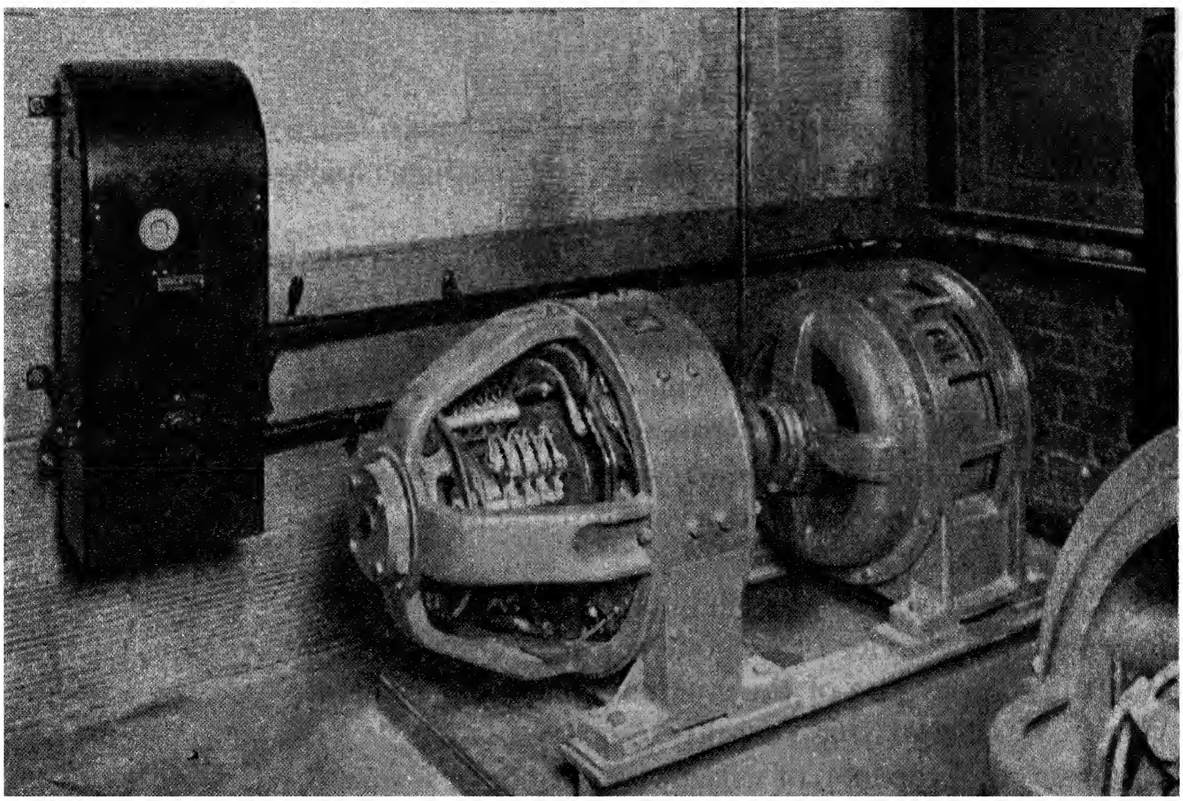


FIG. 257. A battery-charging motor-generator set. (Courtesy of the General Electric Company.)

way electron valves. The principle of these tubes will be explained in the next Section of this Unit.

Copper-copper oxide rectifiers depend upon the fact that electrons can flow readily from the metal into and through the oxide film but cannot flow in appreciable amounts in the opposite direction. A cell containing a plate of aluminum and a plate of lead or some other metal dipping into a solution of some substance such as borax shows a similar rectifying action at the surface of the aluminum electrode.

The mercury-arc rectifier is another common type of rectifier that was formerly widely used for charging batteries and is the most important method today for converting alternating current to direct current.

STUDY QUESTIONS

1. How would you proceed to transform a current of low voltage to one of high voltage by the use of an induction coil?
2. Why do not alternating-current transformers have a make-and-break device?
3. How would you make a transformer (*a*) step up voltage, (*b*) step down a voltage?
4. Discuss Faraday's contribution to electromagnetism.
5. What is the purpose of the oil in a transformer?
6. How may a voltage be induced in a conductor?
7. What determines the strength of the voltage produced by moving a coil of wire through a magnetic field?
8. What is a transformer?
9. How do transformers differ from induction coils?
10. How is the high voltage necessary to produce sparks in an automobile obtained?
11. How could one change a 10-volt current to a 100,000-volt current?
12. Why is electrical energy transmitted over long distances at high voltage?
13. Give five examples of the use of transformers.
14. Count the transformers that you can see on your way to school.
15. State the three laws of electromagnetic induction.
16. Why is an alternating current used in transmission lines?
17. When a transformer raises the voltage of a circuit, does it increase the power? Why, or why not?
18. Explain the action of the telephone.
19. Explain the behavior of a choke coil.
20. What is the purpose of the condenser in the Tesla coil?
21. What is an alternating current?
22. If the speed of the loop of wire in the generator is increased, what is the effect on the current?
23. Would a wire pointing east and west produce an electromotive force if allowed to fall to the ground? Why, or why not?
24. Name and give the purpose of the various parts in an alternating-current generator.
25. Describe and explain the action of a magneto.
26. Of what does the simplest motor consist?
27. Upon what does the strength of the current produced by a generator depend?
28. What is meant by a 60-cycle current? Is it direct or alternating?
29. What happens when the direction of the current through a direct-current generator is reversed?
30. List as many ways as you can think of to produce a direct current.
31. List the different methods of rectifying an alternating current.
32. Explain the action of the copper-copper oxide rectifier.
33. What factors determine the electromotive force of a generator?
34. Prepare a list of home devices that are operated by electric motors.

UNIT VII

SECTION 6

ELECTRICAL ENERGY MAY BE CONVERTED INTO HEAT

Introduction.

Many applications of electricity depend upon the conversion of electrical energy into heat. Frequently this conversion takes place to an undue degree when not desired, and it always accompanies the conversion of electrical energy into other forms of energy. Thus, when electrical energy is converted into chemical energy, magnetic energy, or mechanical energy, the process is not 100 per cent efficient because some of the electrical energy is converted into unwanted heat. The quantity of electrical energy can be measured by converting it into heat because this conversion can be made 100 per cent efficient.

When an Electric Current Flows through a Conductor, Heat Is Generated.

The production of heat by an electric current resembles the production of heat by friction; in fact, it is the resistance that the electrons encounter as they pass along a conductor that produces heat. If a conductor offered no resistance to the current, there would be no friction and no energy lost in the form of heat.

As previously mentioned, certain metals and alloys, such as nichrome wire, have a relatively high specific resistance (*i.e.*, a high resistance for a given length and cross section) and are therefore used for electrical heating devices, such as electric toasters, electric irons, electric heaters, electric stoves, and electric heating elements for heating water or other liquids.

Electric welding is a process in which a large current is forced through two adjoining pieces of metal whose resistance causes them to become so hot that they melt together. Several recent destroyers built for the United States Navy were electric welded because it permitted greater strength and rigidity and less weight than are possible with rivets.

Inasmuch as copper wires offer a certain amount of resistance, wires of small diameter will be heated to the point where the insulation is

ignited, thus causing a fire, when an excessive current is passed through the wire. For high-power currents, wires of larger diameter must be used if voltage is kept low, in order to prevent their excessive heating.

Excessive currents pass through wires when they are short-circuited, and many fires in automobiles and homes are caused in this way. A short circuit is caused by connecting two wires through such a low resistance that the current flowing through the wire becomes very great, causing the wires themselves to become hot enough to start a fire or even melt — all because of their own resistance.

In order to avoid such fires, fuses are introduced into the circuit. A fuse is a wire or strip of some metal or alloy which has a low melting-point and a comparatively high resistance, enclosed in a fireproof box. As the current increases, the fuse is melted and the circuit is broken before the copper wires get hot enough to cause any damage. Fuses are rated according to the current strength at which they will melt. Thus, a 10-ampere fuse will allow currents up to 10 amperes to pass but will melt when the current exceeds that strength. All delicate and expensive measuring instruments should be protected from being burned out by use of the appropriate fuses in the circuits in which they are employed. The practice of replacing a burned-out fuse with a penny or some other conductor which will not burn out is dangerous because, although it does permit current to flow once more, it offers no protection and certainly no remedy for the situation that caused the fuse to blow out.

A short-circuited line is not the only cause of fuses blowing out. If too many electric appliances are connected in a line that is not designed to carry such a heavy load, the fuse will burn out. Large circuit-breakers are used in power substations to protect the equipment against very strong currents that may be produced by lightning or power-system faults. Lightning is the most common source of failure of power during thunderstorms. Sometimes the current is restored at once by merely replacing the fuse. At other times, damage done before the fuse had time to melt may have to be repaired before the power can be restored.

The Development of Electric Lamps Is a Record of Continuous Research.

The first type of electric light to be used was the arc lamp, based upon *Sir Humphry Davy's* discovery in 1801 that a brilliant flame, or arc, can be produced by passing a current through a gap between the adjacent ends of two carbon rods. This discovery was of little value until the electric generator made possible the economical production

of large and continuous currents in large amounts. Arc lamps were formerly and are still used in some places for street illumination. They are also used in projectors and other devices requiring small sources of intense light.

In arc lamps the current flows between the tips of the carbons when they are placed in contact with each other. Inasmuch as the contact is rather poor, there is a high resistance which causes so much heat to be produced that the carbon at the tip vaporizes. The carbons may then be separated slightly, and the current is conducted between them by the carbon vapor which is heated to a brilliant incandescence in the process. These carbons have to be replaced frequently because they are gradually worn down by vaporization and oxidation. Other types of lamps which depend upon the glow of mercury vapor, neon, argon, or sodium vapor were discussed in Unit VI, Section 2.

Inasmuch as the carbons in arc lamps require frequent renewals and the mechanism required to move the electrodes to the proper position as they become shorter is expensive and complicated, and because arc lamps are so bright, they are not satisfactory for small-scale indoor use. For this reason many attempts were made to design a lamp in which a filament could be heated to incandescence.

Incandescent-filament Lamps Were Invented by Thomas Edison.

Thomas A. Edison (1847–1931) was the world's leading inventor. An inventor is not necessarily a scientist, for his researches are in the field of applications of known knowledge rather than in the realm of new contributions to knowledge. Both types of research are important, and it is a wonderful thing for a man to have ability to do both. Only a few men have this ability; two of them, *Lord Kelvin* and *James Watt*, have already been mentioned. Both the scientist and the inventor are benefactors of mankind. Thomas A. Edison was a great inventor because he had fertility of resource, quickness of perception, and, above all, unusual persistence. When Edison needed a material to use for the filament of the incandescent electric lamp, he searched far and wide for vegetable fibers that might carbonize properly and finally used a strip of carbonized bamboo for the filament in his first lamp.

Among Edison's many important inventions were the phonograph and the telephone and telegraph improvements already mentioned. He invented the mimeograph machine, the dictaphone, the motion-picture machine, and a host of other devices.

Edison's first lamp, made in 1879, employed a carbon filament in an evacuated bulb. If air were left in the bulb, the carbon would be oxidized at once. For twenty-five years the carbon-filament lamp,

with slight modifications, was used. A few such lamps are even now in use. In 1906 the carbon filament was replaced by the more economical tantalum and tungsten filaments, which can be heated to higher temperatures and yield a whiter light. The early tungsten-filament lamps were not very successful because the tungsten filament was so brittle and fragile that it broke easily and because it vaporized so rapidly that the lamps had very short lives. *W. D. Coolidge*, of the Research Laboratory of the General Electric Company, worked for many years trying to accomplish the "impossible" feat of making tungsten ductile. At last his indomitable perseverance, backed by excellent facilities, brought the triumph that made the modern, inexpensive, economical electric lamp possible. This invention did not solve all of the lamp manufacturer's problems. The bulbs began to blacken soon and grew blacker with use. It was found that the blackening produced by the vaporization of the tungsten filament and its subsequent deposition on the glass could be greatly decreased by adding an inert gas like nitrogen or argon. This caused a decrease in the efficiency of the lamps due to the heat transmitted by the gas, but this was more than overcome, in turn, by using concentrated filaments or coils of filament. On the other hand, higher temperatures were made possible, and a better, whiter light was produced. The modern gas-filled tungsten-filament lamp uses about one-fifth to one-sixth as much power as the carbon-filament lamps for the production of the same amount of light. Progress is still being made in the production of lamps with longer lives which produce more light at lower cost. For example, a simple change in the construction of 60-watt lamps in the United States alone gave users $12,000,000 worth of additional light for their money in a single year.

Incandescent lamps of considerable power have been developed so that 500- to 1000-watt lamps have now largely replaced arc lights in projection machines. Lamps of even greater power are used for certain purposes.

Two recent types of lamps are the photoflood lamp and the photoflash lamp. The photoflood lamp gives an intense white light, with some ultraviolet radiations, and it can be used as a source of such radiations. When photoflood lamps are used in the ordinary lighting circuits, the filaments are heated to an intense white heat. In this case the intensity of the light is more important than the length of life of the lamp, which is only a few hours. The photoflash lamp contains thin aluminum foil or wire, which burns with a flash in the oxygen gas in the bulb when the current is turned on; the current from a small dry cell is all that is required.

Operating Economy of Electric Lamps Depends upon the Voltage of the Circuit in Which They Are Used.

It is important to select electric lamps which are designed for use with a given lighting circuit. If a 110-volt lamp is used with a 120-volt circuit, it will give about one-third more light than it would with a 110-volt circuit; but its life will be only about one-third as long because the temperature to which the filament is subjected is too high. On the other hand, a 120-volt lamp when used with a 110-volt circuit will last about two and one-half times as long, but it will give only 74 per cent as much light as it would if it were operated at 120 volts.

Electric Current May Be Produced from Heat.

Just as mechanical energy can be converted into electrical energy and electrical energy can be converted back into mechanical energy, so we shall see later that the conversion of chemical energy into electrical energy can be reversed and, to a certain extent, the conversion of electrical energy into heat energy can be reversed. This latter process is not efficient, however, and has little practical application.

The direct conversion of heat energy into electrical energy is called the *thermoelectric effect.* All metals, some nonmetals, and many compounds emit electrons when heated. When two dissimilar metals joined together are heated, there will be a flow of electrons from one metal to the other because of the difference in their tendency to emit electrons. Thermocouples and thermopiles, which consist of a series of thermocouples, serve as devices to measure temperature because the increase in current registered by a galvanometer is closely proportional to the rise in temperature for certain combinations of metals. Thermopiles are made so sensitive that they can detect the heat from distant stars which changes the temperature only 0.000,000,1° C.

It is interesting to note that there is an inverse thermoelectric effect in which the temperature of a junction between two metals changes when a current passes through the junctions.

Heating Effects Are Also Produced by High-frequency Currents.

The General Motors Corporation exhibited a combination refrigerator and stove which they called the *Frig-o-Therm* at the World's Fair in 1940. The cooking was accomplished by means of an alternating current having a frequency of 100,000 per second. Each alternation induces a current in the iron skillet and thus causes it to get hot. The induction furnace works on this principle.

High-frequency currents may be used to heat the human body. In diathermy treatments with high-frequency currents, very large cur-

rents are induced in the body; but as the frequency is decreased the amount of current which the body can stand likewise decreases.

Strong electric shocks may cause death; but, on the other hand, electric shocks are now being used to shock victims of anaesthesia back to life and to bring patients back to sanity from the living death of mental disease.

STUDY QUESTIONS

1. Why are fuses used in all household lighting circuits?
2. What causes a fuse to blow out?
3. Explain the principle of arc lamps.
4. Why does a penny not serve as a good substitute for a fuse in a household lighting circuit?
5. Differentiate between science and invention.
6. Why are gases used in some filament lamps?
7. Explain the action of the photoflash lamp.
8. Explain the so-called "neon" lamps.
9. What is the thermoelectric effect?
10. How has the development of electric lighting affected civilization?
11. Our electricity bills are rated in terms of kilowatt-hours. What measurement is expressed in kilowatt-hours?
12. State Joule's law.
13. What is the relation between the resistance of a wire and its diameter?
14. What current will flow in a lamp whose resistance is 200 ohms when in a 110-volt circuit?

UNIT VII

SECTION 7

THE GENERATION AND RECEPTION OF ELECTRO-MAGNETIC WAVES ARE THE FUNDAMENTAL PROBLEMS OF THE RADIO

> The real credit for everything that has been done in the field of wireless belongs, as far as such fundamental credit can be definitely assigned to anyone, to Professor Clerk Maxwell, who in 1864 carried out certain abstruse and remote calculations in the field of magnetism and electricity. — Abraham Flexner.

Introduction.

The majority of the great scientific developments of today represent the contributions of research men working in many different laboratories throughout the world. Each man adds his bit to the final result, but few discoveries are outstanding in themselves. There are usually a few pioneer discoveries of fundamentals upon which all future work is based. In this Section we shall study the basic principles of the transmission and reception of electrical energy in the form of electromagnetic waves, upon which the modern radio is founded.

Maxwell Originated the Electromagnetic Theory of Light.

In 1864 *Clerk Maxwell*, the great English mathematical physicist, reached the conclusion from his calculations that all forms of radiant energy are nothing more or less than electromagnetic waves.

The "lines of force" studied in magnetism and in current electricity are thought to exist for every electron. These "lines of force" represent a convenient fiction to express the "field of influence." When the electrons are in a regular position, the field of influence becomes evident, as in the case of magnets, because of their ability to repel or attract bodies surrounded by similar fields of influence. When electrons are in no regular position with relation to each other, as is true in nonmagnetized matter, fields of influence surrounding the electron neutralize, rather than reinforce, each other. When electrons move in one direction, as in a current of electricity, there is a motion of these fields of influence. Now, what would happen to the field of influence if the electrons were to oscillate back and forth? According to Max-

well's theory, waves would be set up which would travel out in all directions from the vibrating electron. A luminous body is considered to have within it countless vibrating electrons passing from one energy level to another, which cause the electromagnetic waves that we call light. A heated, nonluminous body would also contain vibrating electrons, but the amplitude of the vibration would differ from that in a luminous body, and the wave length of the resulting electromagnetic waves would therefore be different. In this case such waves would be called infrared, or heat, waves.

Hertz Produced Electromagnetic Waves by an Oscillating Electric Charge.

The German physicist, *H. Helmholtz*, suggested to one of his brilliant students, *Heinrich Hertz*, that he attempt to obtain experimental proof of Maxwell's theory. Hertz accepted the challenge. His first problem was to determine whether or not electromagnetic waves would travel through space without a conductor. While working on this problem, he observed a tiny discharge between the extremities of

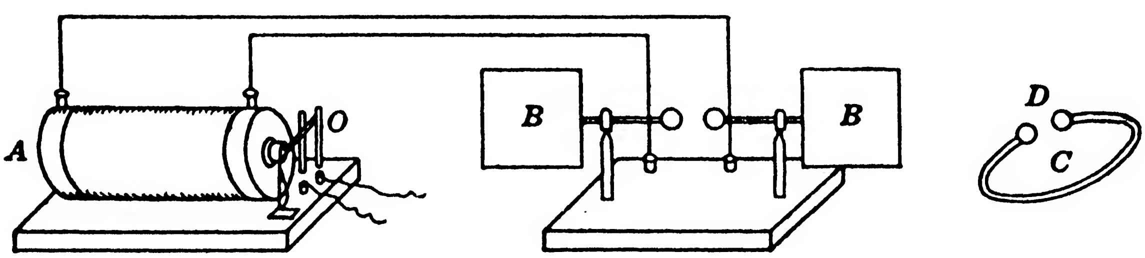


FIG. 258. Apparatus used by Hertz to demonstrate that electric oscillations produce electromagnetic waves.

a flat coil when a nearby Leyden jar was producing an electric discharge between two knoblike terminals. This gave him the clue to the knowledge he was seeking. He produced an oscillating charge by connecting the terminals of an induction coil, *A* and *O*, to two metal plates, *B* and *B*, which acted as a condenser. By the simple process of charging and discharging this condenser, he produced electric oscillations. That these oscillations really produced electromagnetic waves he then proceeded to prove by use of a loop of wire, *CD*, with a small spark gap. He found that when it was properly oriented sparks jumped across this gap in the loop of wire at the same instant that they jumped between the terminals of the induction coil across the room. The confirmation of Maxwell's electromagnetic theory of radiation was one of the greatest advances ever made in the realm of physical science, because it not only presented a principle by which knowledge of radiant energy could be coordinated, but it paved the way for wireless telegraphy and the radio.

Marconi Invented the Wireless Telegraph.

Hertz considered the possibility of using these "wireless" waves for communication but he could not devise a method to detect the wave at a distance. Discoveries of other men furnished the basis for wireless wave reception, but it remained for Marconi to work out its first use in actual communication.

Guglielmo Marconi (1874–) improved the sending apparatus so as to give waves of greater intensity. The plates of the condenser had to be enlarged, and Marconi conceived the idea of using a system of wires (or antennae) supported high in the air as one plate of the condenser and the ground as the other plate. A high-frequency induction coil operated by a battery produced the current, and the signals were produced by making and breaking the current with a telegraph key. The spark was produced between two wires, one leading from the ground and the other leading from the antennae. The spark produced the electromagnetic waves (now called Hertzian or radio waves), which were detected by the receiving set.

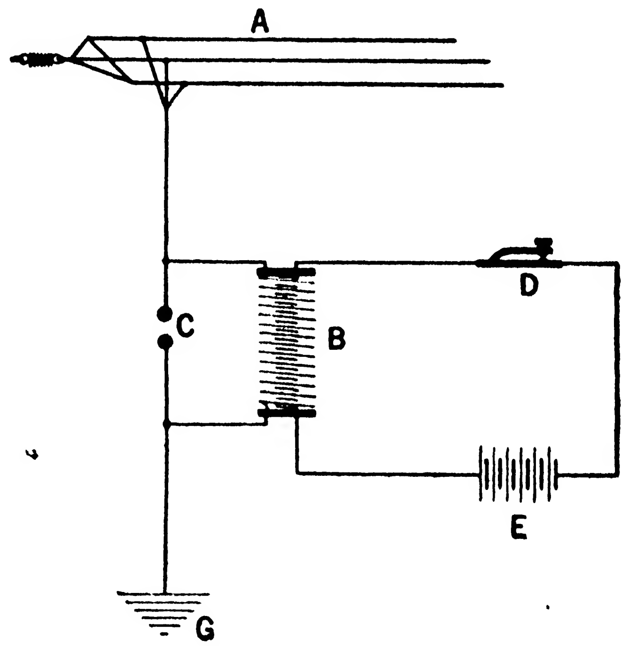


FIG. 259. Marconi's sending apparatus: A, antenna; B, induction coil; C, spark gap; D, key; E, battery; G, ground.

The oscillations in the receiving circuit are very feeble, but their effective reception has been greatly increased by the use of antennae. Marconi used a coherer tube as a detector. The principle of the coherer had been worked out by other investigators, but they did not realize its possibilities. The principle is simple; a tube of nonconducting material, such as glass, is filled with metal particles. When the particles are subjected to electromagnetic waves, they cohere and thus increase the ability of the particles to conduct a current. Marconi used an electric tapper to cause the particles to decohere after each impulse. A current was thus caused to operate a telegraphic sounder so that Morse signals could be received.

An early form of detector consisted of a crystal of galena in contact with a piece of copper wire. Such a crystal permitted the current to pass more readily in one direction than in the opposite direction and thus converted the oscillations into impulses in one direction which could be detected by a telephone receiver. Perhaps some of the

readers of this book have made their own crystal-detector radio receiving sets.

In his earlier experiments, Marconi succeeded in transmitting messages over a distance of two miles. In 1898 he sent messages from Poole to Alum Bay, Isle of Wight, a distance of eighteen miles. By 1910 Marconi had succeeded in perfecting his apparatus to the point where messages could be transmitted six thousand miles.

In 1900 Marconi produced a much improved wireless apparatus. In the first place he added tuning coils, thus removing the interference caused by the increasing number of stations. The tuning coil is a device that controls the wave length of the waves sent out so that the waves of only those lengths desired are sent out.

Today each transmitting station is required by law to use certain wave lengths in order to avoid the confusion of competing messages on the same wave length.

Vacuum Tubes Are Now Used to Receive High-frequency Oscillations.

The crystal detectors were replaced by two-electrode vacuum tubes. Later, three-electrode vacuum tubes were introduced for receiving and ultimately for sending radio waves.

Thomas Edison made the first discovery that led to the modern vacuum tube. In connection with studies to determine the reason why black deposits formed in his incandescent lamps, he placed an insulated plate between the filament and the glass. When this plate was connected with the positive terminal of a battery through a projection fused through the glass and the filament was connected with the negative pole of the battery, a current of electricity was found to flow through the wire. This effect, known as the *Edison effect*, remained unexplained for several years, although Edison rightly concluded that the current somehow leaped across the gap between the plate and the filament. Today we believe that this effect was due to the fact that hot metals emit electrons.

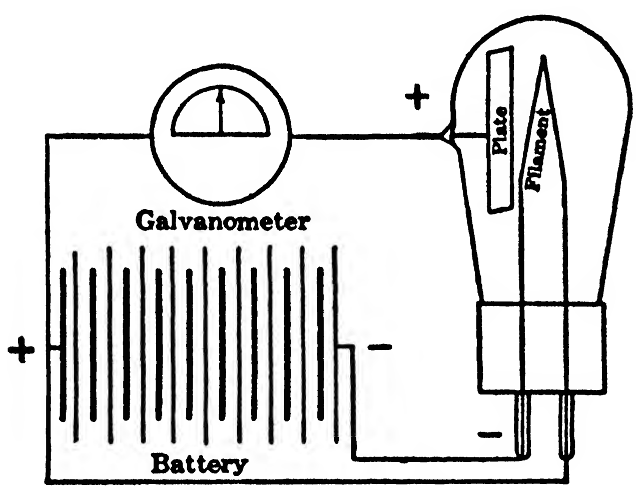


FIG. 260. Apparatus by which the Edison effect may be produced.

The efficiency of this one-way electron valve was greatly increased by using a cylinder bent around the filaments instead of the plate.

The three-electrode vacuum tube represented the next great de-

velopment. *Lee De Forest* and other investigators placed a third electrode, or grid, consisting of a coil, between the heated filament and the plate. In other three-electrode vacuum tubes the coil is replaced by a perforated screenlike metal plate. This grid controls the flow of electrons passing between the filament and the plate because if the grid is charged with electrons it will repel the stream of electrons flowing from the filament to the plate. On the other hand, if the grid is positively charged relative to the cathode, it produces an opposite electrostatic field which causes a heavier stream of electrons to flow from the hot filament than would otherwise leave it. Because the grid is much closer to the cathode, a given change in grid voltage has a much greater effect on the total emitted current than an equal change of plate voltage. The operation of the tube depends upon grid *voltage*, not current, thus making it possible to produce large changes in current (thus power) in the plate circuit for very small input power to the grid. If the grid is furnished with a varying potential, corresponding variations in the flow of current through the tube will be produced. Inasmuch as the variations in the current flowing from the filament to the plate may be very much greater than the variations in the grid potential, it is possible to use the tube to detect and amplify variations of current that could not otherwise be observed.

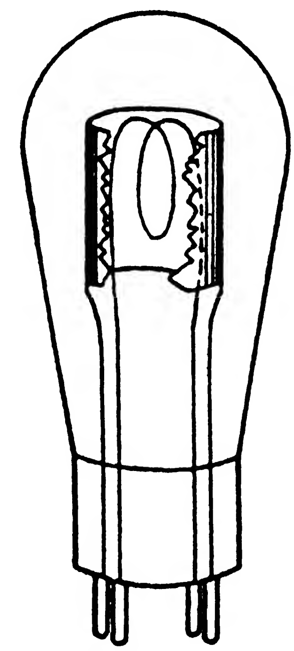


Fig. 261. A cylindrical plate, the invention of Sir John A. Fleming, arrested the electrons as they departed from the filament or cell sides and thus greatly increased the efficiency of the "electron valve."

Remember that an electric current is produced in a conductor when the conductor moves in relation to electromagnetic lines of force (fields of influence). Figure 262 shows a one-tube radio-receiver hook-up. Here the feeble current produced in the antennae by the moving electromagnetic waves induces a current in the grid circuit. The variations in the grid circuit thus produce variations in the stronger current passing between the filament and the plate. The remaining requirement is to place a telephone receiver or loud-speaker in this circuit and to place a grid condenser and leak in parallel between the grid coil and the grid. The variable condenser is used to tune the set to a given broadcast frequency.

Very faint waves from distant stations are intercepted by the antenna and the alternating currents produced by them are fed into a

series of vacuum tubes, each of which amplifies the current that it receives until there is a sufficient amount to operate a loud-speaker.

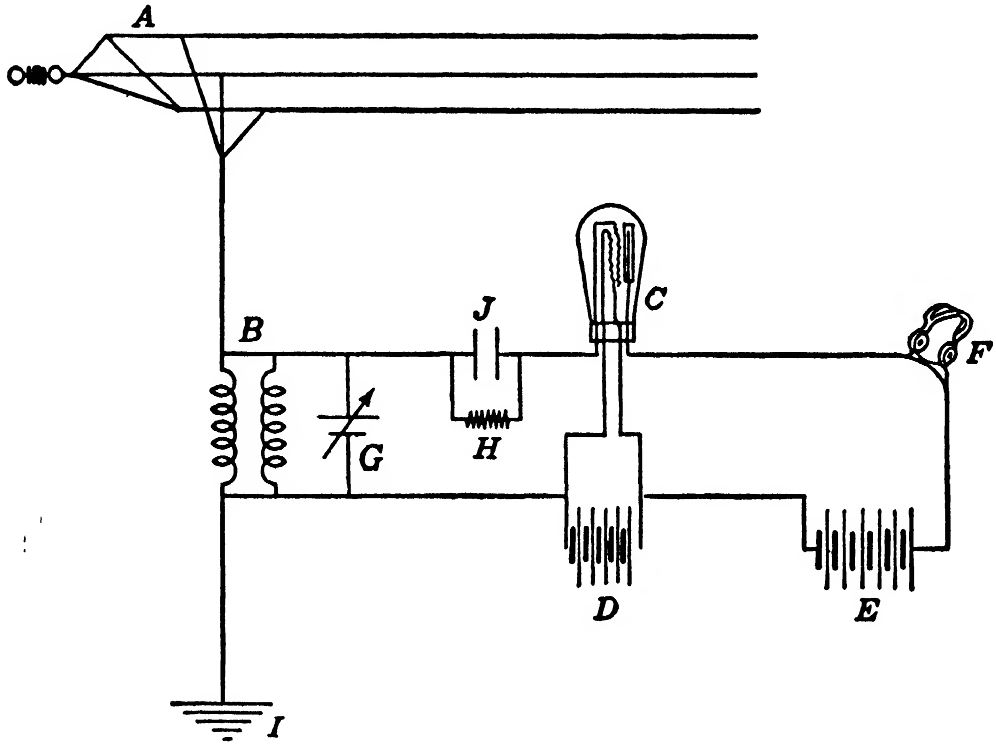


FIG. 262. Diagram of a simple radio receiving set. *A*, antenna; *B*, induction or tuning coils; *C*, detector tube; *D*, the A battery; *E*, the B battery; *F*, receiver; *G*, variable condenser; *H*, grid leak; *I*, ground; *J*, fixed condenser.

A high-frequency radio wave is known as a *carrier wave.* Carrier waves may be sent over power lines or telephone wires, and several messages can be transmitted at one time by using carrier waves of different frequencies.

Vacuum Tubes May Also Be Used to Generate High-frequency Electromagnetic Waves.

In the discussion of the use of the three-electrode vacuum tubes as rectifiers, it was pointed out that such tubes may also be used to produce alternating currents from direct current. Herein lies the value of the three-electrode tube in the transmission of radio waves. If the current from the plate is fed back to the grid, small oscillations in the circuit produced by the tuned circuit will be amplified again and again until an oscillating current of large intensity is produced.

Used as oscillators, such vacuum tubes give oscillations which are very powerful. The ordinary broadcasting oscillator may generate from 35,000 to many millions of waves per second; the frequencies used in the United States range from 550,000 to 1,500,000 per second.

Sound waves in the microphone vary the current in the oscillator and thus modulate the amplitude of the waves sent out.

The older radio sets required batteries for their operation, because of the necessity for a direct current. The direct current is now produced from alternating currents by the use of rectifier tubes, as mentioned in Section 5 of this Unit. A transformer is used to step down the voltage of the current for the filament.

The Klystron Will Produce Ultrashort Radio Waves with Considerable Power.

Short-wave broadcasting is of advantage because less energy is required in broadcasting, inasmuch as the waves can be focused. As a result of focusing the waves, secrecy is made possible. Short waves also make blind landings of airplanes more practicable. More broadcasting stations are possible because the number of frequencies is greater for a given broadcast range. Thirty thousand stations could broadcast in the range between 9 and 10 centimeters without interfering with each other. This is of especial value in television, inasmuch as no television station can broadcast beyond the horizon.

The ordinary triode radio tube is not capable of delivering ultrashort waves, partly because ultrashort waves which complete a cycle in 1/1,000,000,000 of a second do not give enough time for electrons to pass from the negative plate to the positive plate between changes in plate voltage.

W. W. Hansen developed the Klystron, which consists of two rumbatrons. The principle of the rumbatron is that pulsations are produced by changing the velocity of a stream of electrons, rather than by shutting off and on a current of electrons. The Klystron produces ultrashort waves which are as efficient as long radio waves and thus makes possible important advances in short-wave radio broadcasting.

Already ultrashort waves have been employed successfully to relay television programs, thus making possible television network systems.

In 1940 the Klystron tube was used to demonstrate the transmission of power in which members of an audience held flashlight bulbs that were lighted by short waves transmitted from a Klystron tube located on the platform of an auditorium. It is interesting to note that these short waves, unlike ordinary radio waves, do not penetrate nonmetallic materials such as wood.

Loud-speakers and Microphones Added Much to Radio Broadcasting and Reception.

Less distortion and greater volume of sound are obtained with the use of loud-speakers than were obtained with telephone receivers. In

loud-speakers of the dynamic type the current is sent through a coil of wire attached to a cone-shaped diaphragm. This coil surrounds a permanent magnet or an electromagnet operated by a steady current. As the current in the coil varies, it causes the coil with attached diaphragm to vibrate back and forth. This can be easily understood when one considers that the current passing through the coil sets up an alternating electromagnetic field which interacts with the field of the magnet. The vibration of the cone sets up sound waves. Large cones operated by strong currents may set up sound waves which will enable the voice to be heard at a distance of a mile or more.

Loud-speakers and electrical amplification have practically rendered obsolete the old mechanical type of amplification in phonograph machines, and they are now widely used very effectively whenever it is desired that a speaker be heard by large crowds. A combination of amplifier, loud-speaker, and microphone is called a public-address system. Microphones were formerly based on the same principle that is employed in carbon-particle telephone transmitters except that a double button, with carbon granules on each side of the diaphragm, permitted more faithful reproduction. These were too poor in response and produced an undesirable hiss that led to their abandonment. Modern studio microphones are of the condenser type, in which one "plate" of a condenser is a light metal diaphragm whose motion, caused by sound waves, alters the capacity of the condenser and thus produces oscillations in the circuit. A number of other types of microphones are also used today, including piezo-electric crystal types.

Electrical Transcription Was Made Possible by the Electrical Phonograph Pickup.

The electric phonograph resembles the public-address system except that an electrical phonograph pickup replaces the microphone. The needle in one type of pickup is mounted in a movable frame suspended between the poles of a permanent magnet. The needle is surrounded by a coil of wire in which an alternating current is induced as the vibration of the needle causes a variation in the strength of the magnetic field between the poles of the magnet. The needle is caused to vibrate as it follows the wavelike path on the phonograph record. The current induced in the coil is then amplified by means of amplifying-tubes until it is powerful enough to operate a loud-speaker.

An electric phonograph gives a more faithful reproduction than the former mechanical amplification of the nonelectric phonographs because the vacuum-tube amplifier amplifies all frequencies within limits and uniformly within limits.

Automatic Volume Control Eliminates Fading.

Modern radios which have automatic volume control prevent fading by using a portion of the radio waves to produce a control current that increases or decreases with the strength of the grid waves, which is then used to change the amplification of the receiver.

Frequency Modulation Eliminates Static.

Edwin H. Armstrong invented frequency modulation, which is a system of broadcasting whereby static is largely eliminated and more exact reproduction of tonal qualities is made possible. Better reproduction is achieved by using a greater frequency range than is employed in ordinary radio broadcasting.

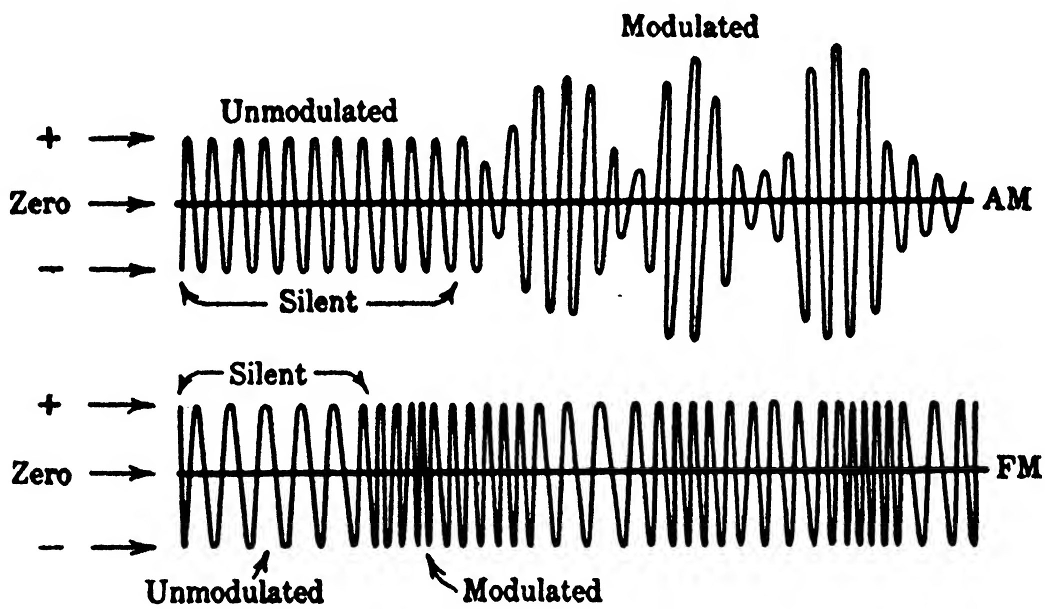


FIG. 263. Amplitude modulation (AM) and frequency modulation (FM). (Courtesy of *Quest Science Summary.*)

Modulation refers to the changes which take place in a radio wave as it reacts to the electrical impulses caused by sound waves. Radio broadcasting stations have been using amplitude modulation in which the strength, or amplitude, of the radio waves varies with the sound that they carry. In frequency modulation, on the other hand, the frequency of the radio wave is varied while its strength is kept constant.

The reason why amplitude-modulation radios have so much static noise is that lightning flashes, diathermy machines, X-ray machines, neon lights, electric razors, automobile ignition systems, dial telephones, thermostats, vacuum cleaners, and similar devices produce electromagnetic waves, some of which have the same frequency as that of the broadcasting station. In the amplitude-modulation radios the only way to overcome this static is to produce such powerful waves that they will overshadow the weaker static waves. In the

frequency-modulation system, the broadcasting station and the receiver are tuned to waves of a certain amplitude so that other waves of the same frequency will not produce any interference unless they are of the same amplitude.

Frequency modulation employs ultrashort radio waves, and therefore broadcasting beyond the horizon is not possible because the ultrashort radio waves are not reflected back to the earth by the ionized layer of gases known as the *Heaviside layer* in the upper atmosphere as are the longer radio waves. This limitation of frequency-modulation broadcasting would really be an advantage because there would not be any interference from distant stations. The range of frequency-modulation broadcasting stations is constant both day and night.

If two stations using frequency modulation were broadcasting on the same frequency, only the more powerful station would be heard.

Frequency modulation makes possible many more broadcasting stations and makes operation costs of a station much lower because less power is required.

Facsimile Broadcasting Has Many Possibilities for Important Applications in Modern Life.

Tabloid newspapers are already being broadcast by a number of radio stations. These newspapers are received and printed by instruments similar to those that transmit photographs by wireless. They are capable of printing five $8\frac{1}{2} \times 11$ pages an hour. Plans were under way in 1940 to print newspapers on ocean liners by facsimile from shore transmitters. Facsimile broadcasting is four times as fast as teletype. It is now being installed in police cars to transmit photographs of wanted criminals, fingerprints, and messages which are thus available in a permanent form.

One might well imagine a vast system of facsimile broadcasting that would take the place of our mail system for many short communications where time is important, thus filling the gap between telegraph and mail facilities.

The Radio Has Revolutionized Communication.

The dramatic evolution of the radio within one decade from a mysterious plaything to the almost universally accepted instrument of entertainment and mass communication has few counterparts in social history. Commercial broadcasting was begun only in 1920, and yet twelve years later it was estimated that over sixteen million receiving sets were in use. The radio and the other agencies of com-

munication, such as the telephone, the telegraph, and rapid mail systems, have brought extreme complexity to modern society, but at the same time they have made for greater homogeneity. The radio, perhaps more than any other development of recent years, has helped to curtail the trend away from the home.

The radio, television, and the sound motion picture present an opportunity for powerful interests, private or public, to indoctrinate the people with prepared opinions.

FIG. 264. Radio facsimile receiver. Courtesy of the R.C.A. Manufacturing Company, Inc.)

The management of communications may well be the most critical factor in maintaining liberty. One of the great problems facing American democracy is that of so managing its communications that free discussion and criticism and unbiased and unlimited dissemination of knowledge may be maintained. Government control should not be of the type found in totalitarian states, where the government determines what is to be spoken or printed. Government control of communications in a democracy should exist only to maintain the freedom of communications and to prevent them from being used for dishonest and debasing purposes.

STUDY QUESTIONS

1. How did Hertz prove that electromagnetic waves would travel without wires?
2. What is the principle of the coherer tube?
3. Give a brief discussion of Marconi and his work.
4. What contribution did Edison make to the radio?
5. Explain what is meant by *tuning*.
6. Explain the action of the vacuum tube. For what purposes may vacuum tubes be used?
7. How are electromagnetic waves produced?
8. Describe the different types of vacuum tubes, and give the use of each.
9. What is the function of the ordinary radio receiving tube?
10. Discuss the social consequences of the development of the radio.
11. What is the principle of microphones?
12. What is the principle of the dynamic loud-speaker?
13. How does frequency modulation differ from ordinary radio broadcasting?
14. What are the advantages and disadvantages of frequency modulation?
15. What is meant by thermionic emission?
16. Point out the fallacy in the following example of reasoning: "Egyptologist: There is nothing new under the sun. Recent excavations in Egypt have brought to light very old wires which make it highly probable that telephones were already used by the Egyptians in the time of Pharaoh.

    "Assyriologist: The Assyrians and Babylonians were even more advanced than that. No wire has ever been discovered during excavations in Mesopotamia. This makes it highly probable that the ancient Assyrians and Babylonians were already familiar with wireless." [1]

[1] A. Wolf, *Exercises in Logic and Scientific Method*, George Allen and Unwin, Ltd., 1933, p. 23.

electroscope will be discharged when the air near them becomes a conductor.

Air can be ionized by ultraviolet light, X rays, radioactive rays, or by the impact of rapidly moving electrons or gas molecules. In short, any form of energy that can excite the molecules is apt to produce ions. Inasmuch as gases always contain some ions, a sufficiently strong electric field will cause those ions to move toward the electrodes with sufficient velocity to ionize molecules which they strike, thus producing additional ions. The ionization process is cumulative because the electrons thus set free ionize still other molecules, and eventually there are sufficient ions to conduct the electric current. Very high potential differences are required to give these free ions a sufficient velocity to start this process of ionization. In air, at ordinary pressures, the potential varies from 10,000 to 30,000 volts per centimeter, as already mentioned. If the pressure of a gas is reduced, a lower potential difference is required to produce ionization. This is because there is enough room between subsequent collisions to permit the electrons to attain high velocities. The gas-filled glow tubes already discussed conduct the electric current because the gases are present under a greatly reduced pressure.

The Aurora Is Thought to Be Similar in Principle to a Gas Discharge Tube.

The transcendent beauty of the aurora is thought to be due to the ionization of the rarefied gases in the upper atmosphere by the ultraviolet radiations or other forms of energy from the sun. The gas molecules in the highly rarefied atmosphere become activated and produce a glow similar to that in a fluorescent tube. The aurora occurs between the heights of 45 and 600 miles above the earth's surface. The aurora may thus be considered to be a type of electric discharge in a rarefied gas.

William Crookes Discovered That Gases Are Ionized More Readily at Reduced Pressures.

Heinrich Geissler, a German glass blower, became famous for his vacuum tubes of various shapes which produced beautiful displays when an electric current was passed through them. By using different kinds of glass, he obtained fluorescent effects of different colors. Such tubes are still called *Geissler tubes*.

About 1878 *William Crookes* (1832–1919) became interested in Geissler tubes. He made some tubes in which he produced a very high vacuum. Tubes similar to those shown in Fig. 267 are called *Crookes*

tubes. Crookes observed flickering streams of light shooting from the negative electrode to the positive electrode, which he found would cause diamonds, rubies, and other substances to become fluorescent or phosphorescent. The rays would not penetrate mica or relatively thick layers of certain metals but cast a shadow of the pattern in which they were cut.

FIG. 267. Crookes tube for showing the shadow of a cross. (Courtesy of the Central Scientific Company.)

He found that these rays would heat a target placed in their path or cause a paddle wheel to revolve and therefore concluded that the rays consisted of particles having mass.

He also found that a beam of these rays, passed through a slit in a shutter placed in front of the negative electrode (cathode) and made visible by a fluorescent screen placed in its path, was deflected by a magnet.

These discoveries aroused the interest of the whole scientific world as few others have ever done.

Later experiments in which the cathode rays were deflected by both electric and magnetic fields proved that they were negatively charged.

Hertz demonstrated that these rays, which would not penetrate mica or certain other substances, would pass through thin sheets of certain metals, such as aluminum.

In 1894 *Leonard* showed that these cathode rays would affect a photographic plate. He was able to obtain the rays by passing them through an aluminum window at the end of the tube. In 1895 *W. R. Roentgen* studied these rays that had been passed through the aluminum window and found that rays of another kind were emitted by the Crookes tube itself and were produced whenever the cathode rays struck an obstacle, such as a metal or glass target, placed in their path. These were X rays, or *Roentgen* rays, as they are often called in honor

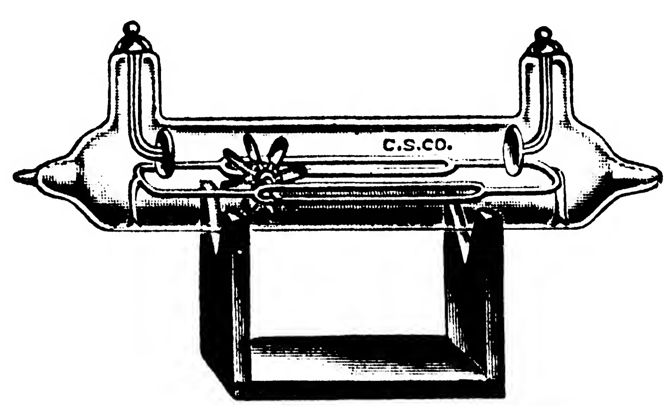


FIG. 268. Rolling wheel tube for showing the kinetic energy of cathode rays (Courtesy of the Central Scientific Cor pany.)

of their discoverer. We will come back to this important discovery later. Let us turn to still other observations.

In 1897 *J. J. Thomson* attempted to measure the speed with which these cathode particles moved and the ratio of their electric charges to their masses. In October, 1897, he made an historic experiment in which he found that the cathode rays could be deflected by a magnetic field. With his apparatus, shown in Fig. 270, he could measure the deflection of the cathode rays by an electromagnet when they passed between oppositely charged plates. The whole apparatus was placed between the poles of a powerful electromagnet. With this apparatus Thomson was able to show that the ratio of the charge on each particle to its mass was constant, regardless of the nature of the electrodes or of the gas in the tube. It was suspected that the mass of these particles was very small, but so far neither the mass nor the charge had been actually measured.

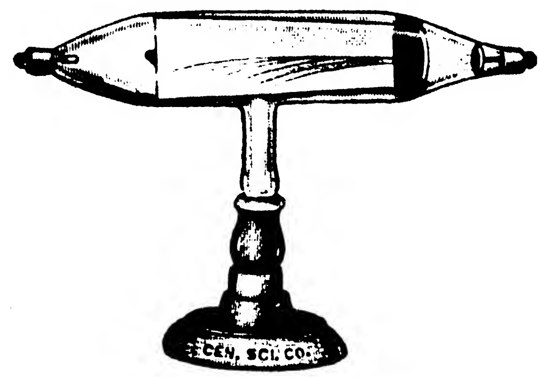


FIG. 269. Vacuum tube to show the deflection of cathode rays by a magnet. (Courtesy of the Central Scientific Company.)

In 1898 and 1899 Thomson measured the value of the charge by the cloud method originated by *C. T. R. Wilson*, later improved by *H. A. Wilson*, and still later further improved by *Robert Millikan*, who confirmed the results of Thomson. This method was based on the fact that these negatively charged particles would act as nuclei to condense droplets of water from moist air. The size of the drops would be determined by the rate at which they would fall. The total quantity of charge used, divided by the number of drops produced, gave the charge per drop.

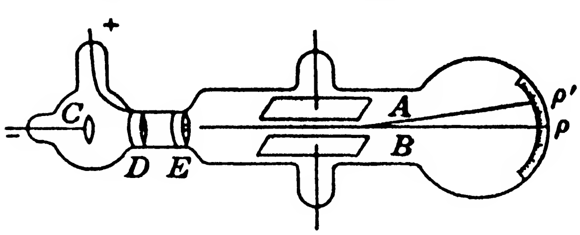


FIG. 270. Sir. J. J. Thomson's apparatus by which the velocity and the ratio of the mass of the electron to its charge was determined. *C*, flat circular cathode; *D*, anode pierced by a central hole; *E*, brass plug pierced by a similar hole; *A* and *B*, parallel plates which establish the electrostatic field; *p* to *p'*, phosphorescent spot deflected by a magnetic field.

The ratio of the charge to the mass, as determined, turned out to be about 1847 times as great as the same ratio for the smallest known particle of charged matter, the hydrogen ion. These cathode particles must, therefore, either carry a charge much greater than that carried by the hydrogen ion or have a much smaller mass. If their charge were the same as that of the hydrogen ion, their mass would be 1/1847

that of the hydrogen ion. The fact, discovered by Thomson, that these particles travel with a velocity nearly a third that of light in a high vacuum when the proper voltage is used suggests that the mass of these particles is very small. Millikan's experiment showed that the charge on these cathode particles is exactly equal, though different in sign, to that of the nucleus of the hydrogen atom. It is now known that these small, negatively charged particles in the cathode rays are the identical electrons mentioned so often in previous sections.

In the Crookes tube there is also a stream of positively charged ions, which travel from the anode to the cathode. These rays have little practical significance, although they have furnished some evidence concerning the structure of atoms, which will be discussed in the next Unit.

X Rays Have Unusual Properties.

Roentgen first observed the evidence of X rays when he shielded a Crookes tube with black paper in a darkened room. A piece of paper covered on one side with a phosphorescent substance became luminous in spite of the fact that the light was covered. This experiment has been described as an accident, but such a combination of circumstances would not occur for many men.

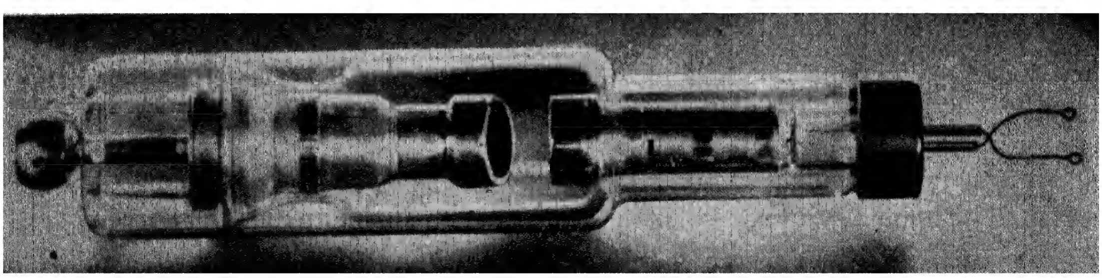


FIG. 271. A shockproof 200,000-volt X-ray tube used for cancer treatment. (Courtesy of the Westinghouse Electric and Manufacturing Company.)

From this experiment Roentgen concluded that those rays would pass through opaque substances. He found that they would pass through a thousand-page book, two packs of cards, and thick blocks of wood. Thin sheets of metal also permitted the rays to pass, but thick layers prevented their passage. When the hand was held between the Crookes tube and the fluorescent screen, shadows of the bones were seen. He then tried taking pictures with X rays and was delighted t find that it could be done. On Christmas Eve, 1895, Roentgen showed his first X-ray pictures to an astonished group of German physicists. Among these pictures were photographs of the bones of his hand and of keys contained in a purse.

These rays were unlike any previously studied, and their relation to cathode rays was for some time unknown, so they were called X rays, X standing for the unknown.

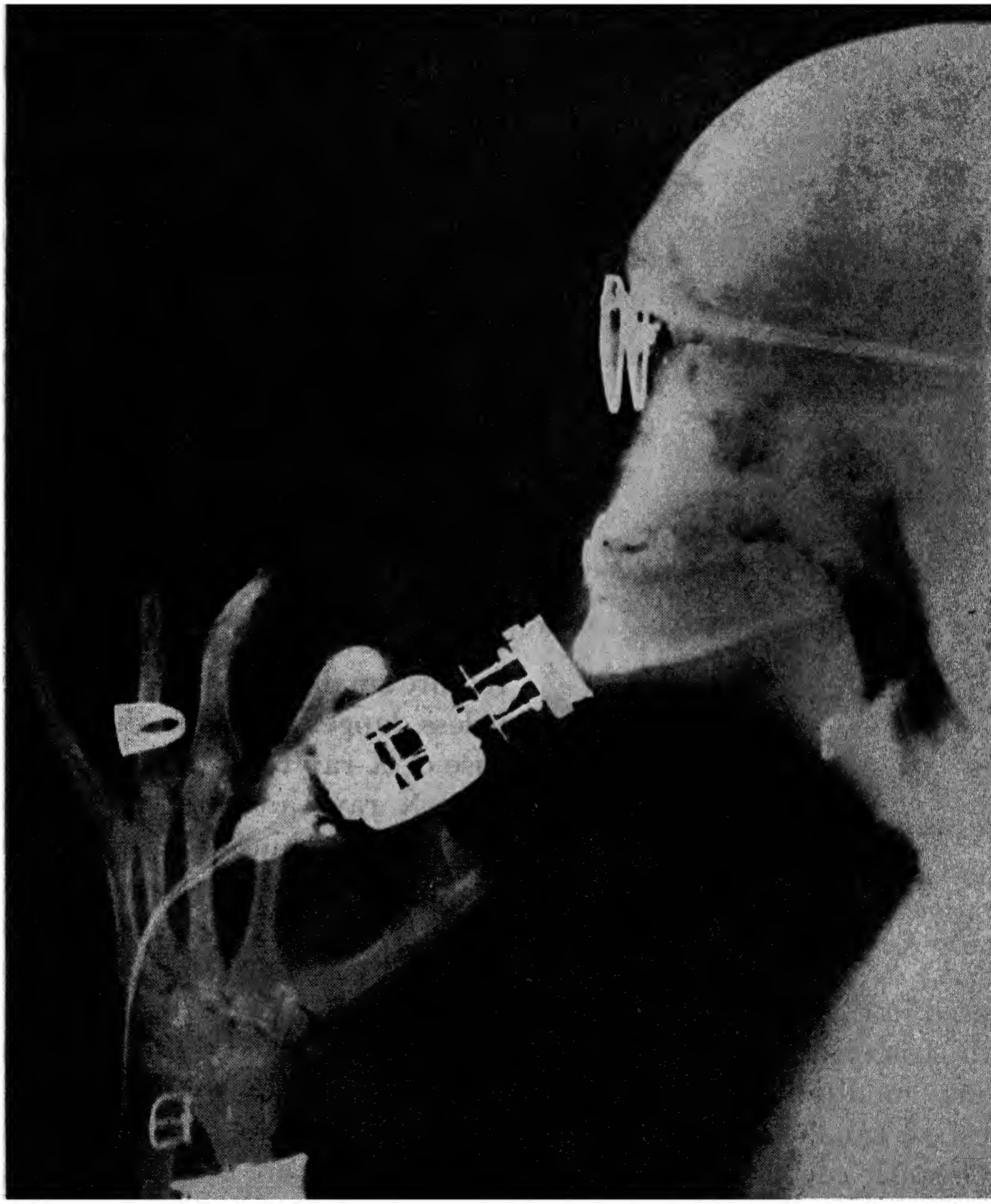


FIG. 272. X-ray radiograph of a man shaving himself, taken with an exposure of 1/1,000,000 second. (Courtesy of the Westinghouse Electric and Manufacturing Company.)

Early X-ray tubes were devised by *Sir Herbert Jackson*, of King's College, London, who refused to patent them and thus permitted a fortune to slip through his hands for the sake of Science. Such sacrifice of personal benefit to the development of Science is not uncommon; true scientists are more interested in the development of knowledge

than they are in personal gain. In fact, a scientist can usually do his best work only when his mind is completely free from financial worries.

In 1913 *W. D. Coolidge* improved the X-ray tube by using a coil of wire heated to incandescence by an electric current to produce a stream of electrons, which were given a high velocity by the application of a potential of 100,000 volts to 1,500,000 volts between the filament and the cold target. The exhaustion of the air was carried to a higher point than in previous tubes, so that harder (more penetrating) rays were obtained. By regulating the voltage applied to the tube, the "hardness" of the rays could be governed. The shorter the wave length, the more penetrating ("harder") the rays are. Very high voltages produce X rays of very high penetrating power. Supervoltage X rays require smaller exposures, and there is less danger of burns than in the case of X-ray tubes of smaller voltage. X rays are widely employed in photographing the bones and organs of the body. A considerable detail of the soft tissues of the body is also revealed, so that X rays can be used in diagnosis. Tuberculosis of the lungs, abscessed or abnormal teeth, fractures, calculi (stones) in the kidneys, and many other abnormal conditions can be detected by X rays. The whole length of the digestive canal can be studied by giving the patient a harmless dose of bismuth carbonate or barium sulfate, which are opaque to X rays and thus show the digestive organs in outline. X rays have to be used with caution because they may cause severe burns that refuse to heal. There were many martyrs to X rays before their harmful properties were recognized and effective means of protection from X rays were devised.

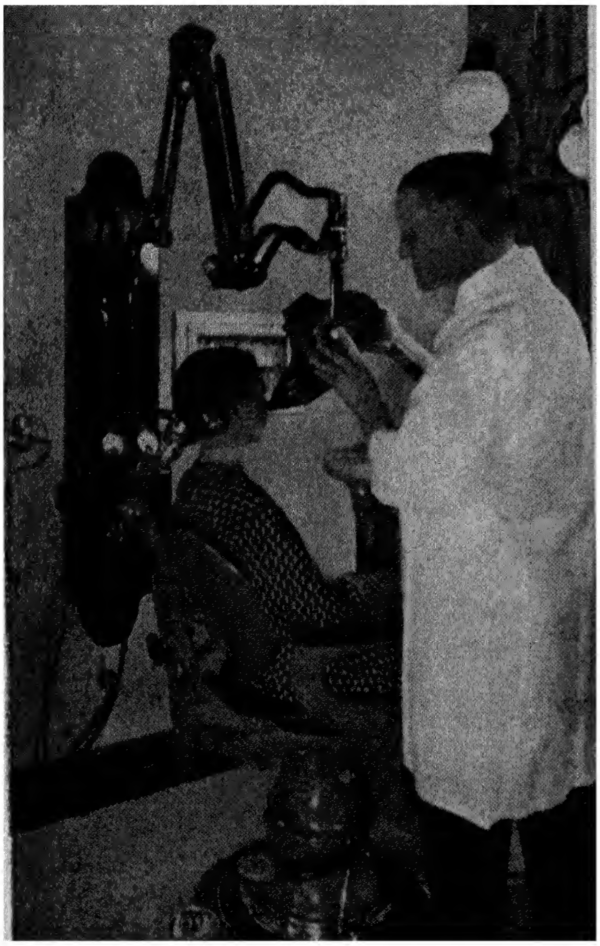


FIG. 273. Dental X-ray unit in operation. (Courtesy of the General Electric X-ray Corporation.)

Besides their use in medicine, X-ray machines have been used in detecting flaws in metals and welds; for example, every weld in the huge pipes used in the Boulder Dam project was X-rayed by a 300,000-volt X-ray machine, and twenty-nine miles of film were used in taking

these X-ray photographs. X-ray machines have also been used to solve paint problems, to determine the cause of differences in physical properties of different samples of graphite, and in the examination of porcelains, papers, electrolytic deposits, patent leather, rayon, asbestos, grease, rubbers, soaps, resins, ice cream, and a host of other materials.

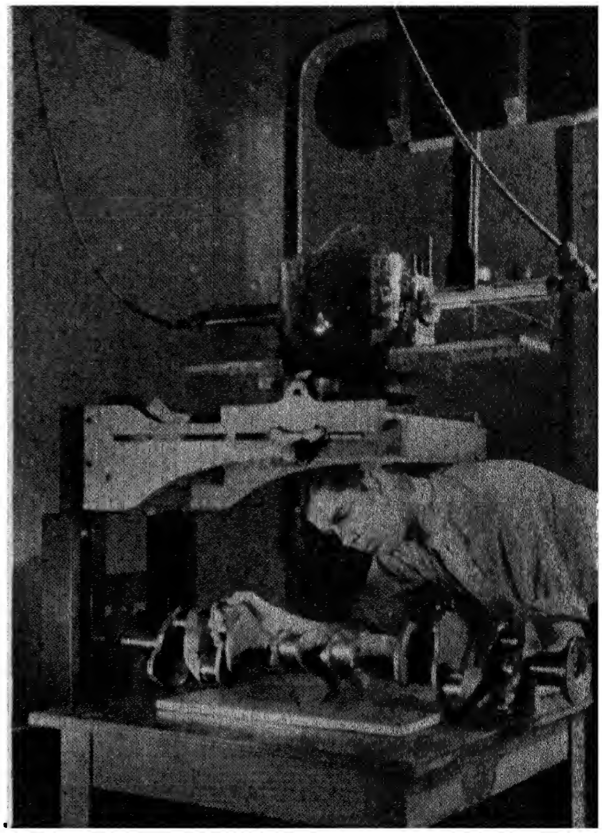


FIG. 274. X-ray photographs locate weak spots in automobile parts. (Courtesy of the General Motors Company.)

Instead of using photographs, the fluoroscope may be used with X rays in observing the body. The fluoroscope depends on the fact that X rays cause a fluorescence in certain substances. An excellent fluorescent screen is produced by coating it with barium platinocyanide.

A recent development is the use of 35-mm. miniature films for X-ray photographs that greatly reduces the cost of X-ray examinations. X rays cannot be bent as light rays can by lenses, and for that reason small pictures cannot be taken by the direct use of X rays. In this new development the subject to be examined is placed between the X-ray machine and a fluorescent screen, and a photograph is made of the resulting image produced on the screen. The camera and film-holder are made of lead to keep out X rays.

The nature of X rays remained a mystery for several years after their discovery. They are not deflected by electric or magnetic fields and are therefore different from cathode rays in that they have no charge. Since they cannot be reflected or diffracted by ordinary means, it appeared at first that they were not electromagnetic radiations similar to light waves. However, it was later concluded that X rays must be electromagnetic radiations of very small wave length — so small, in fact, that no diffraction gratings or prisms would diffract them. In 1912 *Max von Laue* conceived the idea that the distances between atoms in a crystal were just about of the right order to enable crystals to act as diffraction gratings for electromagnetic waves of such a small wave length. The experiment was tried by many workers, and it was

found that diffraction actually took place. This experiment permitted the measurement of the wave length of X rays and thus established the nature of X rays. It also proved to be a valuable tool for the study of the structure of crystals.

STUDY QUESTIONS

1. Under what conditions will the air conduct electricity?
2. How may the air become ionized?
3. How many volts would be required to produce an electric discharge through ten feet of air?
4. What are the important properties of X rays that cause them to be so useful?
5. What is the nature of X rays?
6. What enables a spark to pass between the terminals of an induction coil?
7. How may the ionizing power of a given ionizing agent be determined?
8. Why is it that neon tubes conduct the electrical current through such long distances at relatively low voltages?
9. Describe the properties of cathode rays, and show how these properties were determined.
10. How are X rays produced?
11. List the applications of X rays.
12. Give the principle of the fluoroscope.
13. How was it shown that X rays are electromagnetic waves?
14. Give a theory to explain the aurora.
15. How has it been made possible to take miniature X-ray photographs?
16. What evidence is there that cathode rays consist of a stream of electrons?

*

UNIT VIII

MAN IS MASTERING HIS MATERIAL WORLD THROUGH AN EVER INCREASING UNDERSTANDING OF ITS NATURE

INTRODUCTION TO UNIT VIII

Some of man's greatest achievements in mastering his material world may be found in the transformation of matter. The manufacture of dyes, drugs, perfumes, and high explosives from coal, and the synthetic production of nylon represent chemical changes (changes in the composition of matter). The rest of this text is devoted to the study of the contributions of chemistry to modern living. In this Unit the basic principles necessary to an understanding of the units that follow will be presented. These basic principles are also necessary for an intelligent use of the better things that chemistry will bring to you for better living as long as you live.

What is chemistry? Briefly, chemistry is the science of materials. It deals with the clothes that we wear, the foods that we eat, the metals and alloys that have made possible our modern machines, the glass in our houses, the soap and the water that we use for bathing. We are living in the age of chemistry.

> Chemistry, . . . whose practical value to our civilization can hardly be exaggerated, is valuable more for the control it gives over nature, than for the insight it gives us into nature. The chemist's power of control results, of course, from the insight he has obtained, but it so happens that great depth of insight is not necessary in order to gain great power of control.[1]

[1] J. W. N. Sullivan, *The Limitations of Science*, The Viking Press, New York, 1934, p. 296.

UNIT VIII

SECTION 1

ALL MATTER CONSISTS OF NINETY-TWO ELEMENTS AND THEIR COMPOUNDS

The chymists are a strange class of mortals, impelled by an almost insane impulse to seek their pleasure among smoke and vapor, soot and flame, poisons and poverty; yet among all of these evils I seem to live so sweetly that may I die if I would change places with the Persian King. — *Physica Subterranea.*[1]

Introduction.

In this Section the classification and naming of the materials of the universe will be summarized briefly. For many readers it is merely a review of previous study, and for the rest it will be found that a careful study will simplify the understanding of later sections.

The Greek Philosophers Considered All Matter to Be Composed of the Four Elements: Earth, Air, Fire, and Water.

The Greeks felt that all forms of matter should be reducible to a few elemental forms, and so, by a process of reasoning, they arrived at the conclusion that all materials were made up of varying quantities of one or more of four fundamental "elements" — earth, air, fire, and water. The angels were composed of fire alone, bones consisted of two parts fire and one part each of earth and water, while flesh consisted of equal parts of the four elements.

These four elements stood for different qualities; thus fire stood for warmth, dryness, and motion; water represented coldness, moistness, and fluidity; the earth stood for solidity; while the air stood for lightness (low density).

Empedocles (490–430 B.C.) taught that these four elements act under the influence of love and hate to form more complex substances. Later *Aristotle* (384–322 B.C.) added a fifth element which he called essence, replacing the idea of love and hate. This fifth element, or essence (quintessence), added to such qualities as coldness and wetness, produced the other four elements; for example, fire consisted of quin-

[1] A mediaeval treatise on the physical sciences.

tessence plus hotness and dryness. Aristotle's teachings were accepted for nearly eighteen centuries.

The Alchemists Learned Many Things about the Chemical Properties of Matter.

About three centuries before Christ, Alexandria began to replace Athens as the intellectual center of the ancient world. The Egyptians had long practiced the art of preparing cheap alloys which resembled silver and gold. Under Aristotle's influence, the idea gradually developed that, with the proper essence, base metals such as lead could actually be changed into gold. Many people began experimenting to find this essence. It was, of course, never discovered, but some experimenters actually succeeding in preparing materials that resembled gold and probably believed that they had discovered the important essence. Many other experimenters were outright fakers. When one considers how the "patent medicines" industry flourishes today, he can understand why these *alchemists* were able to exist and even secure the support of kings and rulers in those dark ages of ignorance and superstition. It should be noted, however, that a tremendous amount of knowledge accumulated as a result of these experiments.

In the seventh century A.D. the Arabs conquered Egypt, and *alchemy* became an Arabian art. One of the outstanding Arabian alchemists, *Geber* (721–813), believed that all metals were composed of sulfur and mercury. His influence was still felt as late as 1500 A.D., when *Paracelsus* (1493–1541) held that the three elements — earth, air, and water — were represented by salt, sulfur, and mercury, respectively. Paracelsus was the first of the *iatrochemists*, that is, the chemists who devoted their lives to the search for medicines to cure disease. From his time, the alchemists came to be recognized as rogues, and alchemy acquired a bad reputation. At the same time, the iatrochemists worked earnestly and honestly to obtain new substances that would benefit humanity. Paracelsus described these workers as follows:

> They are not given to idleness, or go in a proud habit, or plush and velvet garments, often showing their rings on their fingers, or wearing swords with silver hilts by their sides, or fine and gay gloves on their hands but diligently follow their labors, sweating whole days and nights by their furnaces. They do not spend their time abroad for recreation but take delight in their laboratories. They put their fingers among coals, into clay and filth, not into gold rings. They are sooty and black, like smiths and miners, and do not pride themselves upon clean and beautiful faces.

The history of alchemy and the iatrochemical period is of great interest, but we must now turn to the early discoveries concerning the nature of matter made by the pioneers of modern chemistry.

Robert Boyle First Distinguished between Mixtures, Compounds, and Elements.

Robert Boyle (1627–1691) early became a member of the *Invisible College*, which consisted of a group of men who met together in England from time to time to discuss philosophical and scientific questions. They adopted the experimental and inductive method advocated by *Francis Bacon*, "being satisfied that there was no certain way of arriving at any competent knowledge unless they made a variety of experiments upon natural bodies." This group of learned men was similar to other groups which sprang up about the same time in Germany, France, and Italy. Later this group developed into the *Royal Society*, one of the world's greatest scientific societies of today.

In 1661 Boyle published his book, *The Sceptical Chymist*, in which he distinguished for the first time between mixtures, compounds, and elements:

> I mean by elements certain primitive and simple, or perfectly unmingled bodies; which not being made of any other bodies, or of one another, are the ingredients of which all those called perfectly mixt bodies are immediately compounded, and into which they are ultimately resolved.

Chemical Changes Are Changes in the Composition of Matter.

Robert Boyle introduced the term *analysis*, which refers to the process of determining the composition of a given sample of material. *Analysis* is simply a method of *separating* materials so that their individual properties may be observed. Some materials are obviously *heterogeneous* in nature; different particles of material exhibit different properties. Granite is an example of a heterogeneous substance; crystals of feldspar are obviously different from the quartz in which they are embedded. A mixture of sand, sugar, and iron filings is obviously heterogeneous, for the white sugar particles can be separated by dissolving the sugar in water and can be recovered by evaporation of the water; and the iron filings may be removed with a magnet. All such heterogeneous materials are called *mixtures;* the test of a mixture is that its ingredients can be separated by physical means, that is, by methods which do not change the composition of any of the components of the mixture.

The sugar, on the other hand, is said to be *homogeneous*, because every particle of it exhibits the same properties. Iron and sand are likewise recognized as homogeneous materials. Any pure (homogeneous) material of invariable composition is called a *substance.* Mixtures are therefore composed of two or more substances which have been intermingled in such a way that the substances have not been

changed in properties. Powdered sugar does not look like granulated sugar, but it tastes sweet. Powdered sugar may be dissolved in water, but it still tastes sweet; and it may be obtained from the water in crystalline form by evaporating the water. Obviously none of these changes has converted the sugar into a new substance but has merely changed its physical properties. Any change resulting in a change in physical properties alone is called a *physical process*.

It is a common observation that sugar may be greatly changed in properties by placing it on a hot stove lid. It is observed to produce smoke and a black material which we recognize as carbon. If the sugar were charred in a test tube, water would also be observed to condense from this smoke in the cooler portion of the tube. It is obvious that new substances have been formed in this case.

Homogeneous substances of invariable composition, such as sugar, which can be decomposed into simpler substances are called *compounds*. On the other hand, one can heat iron to a white heat and can dissolve it with strong acids without decomposing it into a simpler substance. Substances like iron, which cannot be decomposed by ordinary chemical means, are called *elements*.

It is not always easy to tell whether certain substances are elements or compounds; it is very difficult to decompose sand by heating, and one might consider it to be an element. Methods have been found, however, by which sand can be decomposed into the two elements, silicon and oxygen, so we now know that sand is a *compound*. *Lavoisier* drew up a list of substances recognized as elements in 1790. This list included a number of elements, such as sulfur, phosphorus, carbon, silver, arsenic, bismuth, cobalt, copper, tin, iron, manganese, mercury, nickel, gold, platinum, and zinc. It also included light, heat, and eight substances now recognized as compounds. Among these were sand and compounds of oxygen with other metals (calcium, magnesium, barium, and aluminum) which, like sand, could not be decomposed by any method known to Lavoisier.

If iron powder and powdered sulfur are intermingled, it will be found that the mixture can be separated by use of a magnet, which attracts the iron but not the sulfur. This mixture may also be separated by use of carbon disulfide, which dissolves the sulfur but not the iron. If the mixture is heated in a test tube, it will start to glow, and soon a new product will have been formed, which is homogeneous in appearance, black in color, is not affected by a magnet, and is not soluble in carbon disulfide. Many other tests may be carried out to show that an entirely new substance has been formed. In this case a compound substance is produced from two elemental substances.

Such changes as the charring of sugar and the combination of iron and sulfur, in which compounds decompose to form simpler substances or in which simple substances combine to form compounds, are called *chemical changes.* Chemical changes produce changes in *chemical properties*, and *chemical properties are those properties which cannot be expressed without referring to a change in the composition of matter. Every chemical change either stores energy or sets free stored energy.* In the next Section we shall learn that chemical changes are not merely *qualitative*, *i.e.*, that they not only represent changes in the kind of materials present, but that they are also *quantitative* — they always involve definite weights of reactants and products.

The Occurrence and Classification of the Elements.

Only about two dozen of the ninety-two elements are used to a very large extent. The following table shows that 99 per cent of the terrestrial matter is made up of about twelve elements.

CHEMICAL COMPOSITION OF TERRESTRIAL MATTER — EARTH, AIR, AND SEA — IN PERCENTAGE

Oxygen	50.02	Potassium	2.28
Silicon	25.80	Magnesium	2.08
Aluminum	7.30	Hydrogen	0.95
Iron	4.18	Titanium	0.43
Calcium	3.22	Chlorine	0.20
Sodium	2.36	Carbon	0.18

Some of the elements have never been prepared in a pure state. Others have no known uses. Still others are so rare that they cannot be used until more abundant sources can be located.

The elements may be classified as *metals*, *nonmetals*, and *metalloids*. The distinctive properties of these different classes cannot be given yet, but metals, with the exception of mercury, are solids under ordinary conditions and are good conductors of heat and electricity; they have a metallic luster in a coherent state and are relatively malleable and ductile. The nonmetallic elements include solids, liquids, and gases, and in general do not exhibit the properties common to metals. The metalloids are elements whose properties are intermediate between those of metals and nonmetals.

How the Elements Were Named.

Inasmuch as the elements have been discovered and named one after another during a period of several thousand years, it is strange that any system in naming exists at all; and this system probably would not exist if it were not for the fact that most of these elements have been discovered during the past century.

No thought of beauty or convenience in use was shown in naming such elements as dysprosium, molybdenum, neodymium, manganese, praseodymium, ytterbium, xenon, and yttrium.

A great many of the elements have names derived from the Greek — for example, hydrogen (water-producing); chlorine (yellowish-green); helium (sun); neon (new).

Some elements are named after the particular localities in which they were discovered or occur — for example, strontium, from Strontian in Scotland.

The Use of Symbols and Formulas Saves Time.

A symbol is the representation of an element; thus H is a symbol for hydrogen, and O is a symbol for oxygen. Many of the elements are known by symbols derived from their former (usually Latin) names. For example, the symbol for *sodium* is Na (from *Natrium*), and the symbol for *mercury* is Hg (from *Hydrargyrum*).

Inasmuch as compounds are composed of elements, the representation of a compound, called a *formula*, is composed of the *symbols* of the elements in the compound. The formula of copper oxide is CuO because it is composed of copper and oxygen.

STUDY QUESTIONS

1. Define *element* and *compound*.
2. What are the three types of elements?
3. How many elements are there?
4. How were the elements named?
5. What was the main idea of the alchemists?
6. Differentiate between mixtures, compounds, and elements.
7. How does a substance differ from a mixture? What are the two types of substances?
8. Give an outline for the classification of matter.
9. Differentiate between chemical and physical changes.
10. What is analysis?
11. Name the four most abundant elements on the earth's surface.

UNIT VIII

SECTION 2

THE ATOM IS THE UNIT OF CHEMICAL CHANGE

All science has one aim, namely to find a Theory of Nature. — Emerson.

Introduction.

In the previous Section it was pointed out that all of the matter in the universe is composed of at least ninety-two elements, which combine to form compounds. In this Section we shall trace the development of the idea of the concept of *atoms as the smallest portions of elements which act as units in chemical changes.*

The Greeks Taught the Existence of Atoms.

The idea that all matter is composed of ultimate divisions, which we call atoms, may be traced at least as far back as 1000 B.C. The Greek philosophers *Leucippus*, *Democritus*, and *Epicurus* advanced a doctrine in the fifth and fourth centuries B.C. which held that matter is made up of individual particles called atoms, or the first beginnings of things, which are immutable and eternal. These particles were supposed to be in constant motion. On the other hand, most of the other Greek philosophers held that matter is continuous — that it is capable of infinite subdivision. *Aristotle* also believed in the continuity of matter, and the long-continued intellectual dominance of his philosophy caused the atomistic hypothesis to fall into oblivion. In the sixteenth century the physicist, *Gassendi*, revived the atomic hypothesis, and in the following century *Newton* gave it powerful support. His views were expressed in the following quotation:

> It seems probable to me that God, in the beginning, formed matter in solid, massy, hard, impenetrable, movable particles, of such sizes and figures, and with such other properties, and in such proportion to space, as must conduce to the end for which He formed them; and that those primitive particles, being solids, are incomparably harder than any porous bodies compounded of them; even so very hard as never to wear or break in pieces; no ordinary power being able to divide what God Himself made one in the first creation.

The Quantitative Nature of Chemical Changes Was Demonstrated by Lavoisier.

The atomic hypothesis remained a mere valueless speculation until the quantitative nature of chemical changes had been established. *Bergman* (1735–1784), *Joseph Black* (1728–1799), and *Henry Cavendish* (1731–1810) all made use of the balance in the study of chemical processes; but it is to the brilliant French chemist, *Antoine Lavoisier* (1743–1794), that is due the credit for introducing the quantitative epoch in chemistry. Until chemical changes were studied quantitatively, there was little opportunity for real progress, so Lavoisier is usually called the "father of modern chemistry."

Antoine Laurent Lavoisier was born in Paris and early showed a great aptitude in scientific investigation, especially in chemistry. He made many practical contributions of importance, such as the improvement of gunpowder. Lavoisier's most important contribution was the introduction of the balance into chemical investigations. With its aid he overthrew the erroneous phlogiston theory of combustion, which assumed that whenever a substance was burned there was lost from that substance a mysterious "phlogiston." Lavoisier showed that combustion is really a combination of oxygen with a substance.

In 1789 Lavoisier advanced the law of the indestructibility of matter, or what is now known as the *law of conservation of mass.* This law simply states *that there is no perceptible gain or loss in weight in any chemical change.*

In 1793 Lavoisier met his death on the guillotine. Despite his great services to his country, the fact that he was a member of the aristocracy and had been associated with a hated tax-collecting company caused him to be sentenced to death by the French revolutionists. *C. S. Minot* said of this event: "Compared with the growth of Science, the shiftings of Governments are minor events. Until it is clearly recognized that the gravest crime of the French Revolution was not the execution of the King but the execution of Lavoisier, there is no right measure of values; for Lavoisier was one of the three or four greatest men France has produced."

Other Quantitative Laws of Chemical Reaction Were Soon Discovered.

The labors of many investigators in the years just following the death of Lavoisier established a second law of chemical change which was quantitative in nature, just as was Lavoisier's law of conservation of mass. This second law, called the *law of definite composition,* stated that *the composition of a chemical compound is definite in nature; i.e., it is always composed of the same elements in the same proportions by weight.*

All chemical reactions were shown to be changes in which definite weights of substances react with each other to produce definite weights of products. If an excess of one of the reactants is present, it will not enter into the reaction but will remain unchanged at the end of the reaction.

The Atomic Theory Was Advanced by Dalton.

In 1807 *John Dalton* (1766–1844), an English schoolteacher, advanced his atomic theory, one of the three or four great theories of physical science. This theory may be summarized as follows:

1. The atom is the smallest division of an element which can exist within its molecules or the molecules of any of its compounds.
2. Atoms are indivisible, eternal, and indestructible.
3. Atoms of different elements differ in chemical nature and have different masses and volumes, but all atoms of the same element are alike in properties and mass.
4. Compounds are formed by combining definite whole numbers of atoms.

The laws of chemical combination are readily explained by Dalton's atomic theory. Inasmuch as the atoms are assumed to be eternal and indestructible, it follows that all matter which is made up of these atoms is therefore indestructible; this is the law of conservation of mass. Inasmuch as molecules are formed by the combination of definite numbers of atoms, each of which represents a definite weight, it follows that molecules have a definite composition by weight; this is the law of definite composition.

The *atom* is sometimes called the *chemical unit of matter*, while the *molecule* is called the *physical unit*. Matter rarely occurs in the form of atoms, but rather in the form of molecules, which usually consist of two or more atoms. Molecules of elements contain usually two or more atoms of the same element, while molecules of compounds necessarily contain two or more atoms of different elements. *Molecules* may be defined as the *smallest particles of a substance that can continue to exist in a free state.* Some elements, such as hydrogen, oxygen, and chlorine, may be obtained in the form of atoms, but unless something else with which these atoms may react is present, they will react with other atoms of their own kind to form molecules of these elements. A few elements — the rare gases, helium, argon, neon, krypton, xenon, and radon — which do not react, exist in the form of atoms. In this case the molecule is said to be composed of just one atom; *i.e.*, the atom and molecule are identical.

In a previous Unit the actual existence of molecules was discussed.

Scientists are not absolutely sure that atoms exist, for one cannot be sure of anything which does not make a direct and unmistakable impression on at least one of his senses. So useful has the atomic theory been in the study of chemical changes and so convincing are the indications of atoms, however, that one might say scientists are just as sure of the existence of atoms as they are of the existence of the stars.

The Relative Weights of Atoms Are Called Atomic Weights.

Dalton worked out relative weights which he assigned to different kinds of atoms. These weights were based upon the weights of different elements which would react with a fixed weight of some reference element. Dalton assumed that all binary compounds consisted of only one atom of each of the two kinds of elements per molecule. At this time the knowledge of valence had not been developed. The *valence* of an element is simply *the number of atoms of a reference element which will combine with, or are equivalent to, one atom of the element in question.* The weight of an element which will combine with eight grams of oxygen was accepted as the *combining weight.* Hydrogen was selected as the reference element, with a combining weight of one. In the compound, ammonia, NH_3, nitrogen has a valence of three, because one nitrogen atom is combined with three hydrogen atoms.

As quantitative information was gained, it was learned that there were several combining capacities for a number of elements. It soon became evident that a simple relation exists between the *combining weights* of the elements and their atomic weights, namely, that *the combining weight multiplied by the valence is equal to the atomic weight.*

Atomic weights are merely numbers which express the relative weights of the atoms of the different elements, compared with oxygen with a value of 16 as the standard.

The *molecular weight* is *the sum of the atomic weights.* The *gram-molecular weight* is *the molecular weight expressed in grams.* In chemical work symbols and formulas always stand for quantities as well as the qualitative composition of substances. Thus:

H stands for 1.008 (atomic weight)
H_2 stands for 2.016 (molecular weight)
O stands for 16.000 (atomic weight)
H_2O stands for 2.016 + 16.000, or 18.016 (molecular weight)

A gram-molecular weight of water, H_2O, is, therefore, 18.016 grams.

The number of molecules in the gram-molecular weight of any substance is called *Avogadro's number,* and its value is 6.062×10^{23}. This

number, which may also be written 606,200,000,000,000,000,000,000 (see page 238), is so large that it is probably outside the range of your vocabulary. All the people of the world could not count this many atoms if they counted at the rate of two per second from the time of their birth to the time of their death.

The actual weight of any atom can be determined by dividing the gram-molecular weight of the element in question by Avogadro's number times the number of atoms in one molecule.

Atomic Weights Form the Basis for Chemical Calculations.

A chemical equation is simply the shorthand statement of a chemical reaction. In the equation

$$\underset{\text{(2 molecules of hydrogen, 4.032)}}{2\,H_2} \overset{\text{(will react with)}}{+} \underset{\text{(1 molecule of oxygen, 32)}}{O_2} \overset{\text{(to give)}}{\longrightarrow} \underset{\text{(2 molecules of water, 36.032)}}{2\,H_2O(L)} \overset{\text{(and)}}{+} 136{,}540 \text{ cal.}$$

$2\,H_2$ stands for 2 molecules of hydrogen, each of which contains 2 atoms of hydrogen; this represents 4 times the atomic weight of hydrogen, or 4.032. O_2 stands for one molecule of oxygen containing two atoms of oxygen. Inasmuch as the atomic weight of oxygen is 16, O_2 stands for 32. Similarly, $2\,H_2O$ stands for 2 molecules of water, each molecule of which contains 2 atoms of hydrogen and an atom of oxygen. Inasmuch as there is no appreciable gain or loss of weight in a chemical reaction, the weight of hydrogen, 4.032, added to the weight of oxygen, 32, used to produce the water, will give the weight of water produced, 36.032.

In this equation "L" stands for "liquid," and the "136,540 cal." means that when 4.032 grams of hydrogen combine with 32 grams of oxygen to form 36.032 grams of liquid water, 136,540 calories of heat are liberated. The + sign on the left-hand side of the equation stands for "will react with," while the + sign on the right-hand side of the arrow stands for "and." The arrow stands for "to give."

Manufacturing processes which involve a change in the composition of matter must be very carefully controlled; the quantities of materials to be used are determined by the chemist after analysis of the materials and calculations based on equations. The cook's recipe for a cake is essentially a chemical equation, for it tells what reactants to use and how much of each. Fertilizers are bought and sold on the basis of their nitrogen, phosphorus, or potassium content. Raw sugar is bought and sold by analysis. Milk is purchased and sold on the basis of the butterfat content. Wheat is bought by large bakeries on the basis of specified qualities which are checked by analysis. The seller must analyze the

wheat for protein, for example, and the baker usually checks this analysis to make sure that he receives what he has paid for. A carload of iron, copper, silver, or some other ore is paid for on the basis of analysis. A small change in the decimal place of the atomic weight of an element might make a difference of thousands of dollars in the amount paid to a large mine each year, for all calculations based on analyses employ atomic weights. It is exceedingly important, therefore, that atomic weights be known as accurately as human ingenuity will permit.

STUDY QUESTIONS

1. Define atom and molecule.
2. State the main points of Dalton's atomic theory.
3. State the law of conservation of mass.
4. What does Dalton's atomic theory explain?
5. State Avogadro's number. What does it mean?
6. What do chemical equations represent? Of what value are chemical equations?
7. What is (1) a molecular weight, (2) a gram-molecular weight?
8. What is a combining weight of an element?
9. What is the relation between the combining weight of an element and its atomic weight?
10. What is valence? What information is required in order to obtain the valence of an element in a given compound?
11. State the law of definite composition.

UNIT VIII

SECTION 3

ATOMS ARE COMPLEX AND MAY BE TRANSFORMED BY NUCLEAR CHANGES

We find ourselves, in consequence of the progress of physical science, at the pinnacle of one ascent of civilization, taking the first step upward out on the lowest plane of the next. Above us rises indefinitely the ascent of physical power — far beyond the dream of mortals in any previous system of philosophy. — Frederick Soddy.

Introduction.

William Prout, having observed that many atomic weights are whole numbers and having assumed that all atomic weights would prove to be whole numbers, advanced the hypothesis that the atoms of all elements are simple multiples of the atoms of smallest mass, those of hydrogen. Prout was on the track of a great idea, but it was not until some of the information presented in this Section became available that his idea that atoms are complex in nature received confirmation.

The Periodic Law Suggests Atomic Complexity.

In 1865 *John Newlands* observed that the elements seem to exist as families. Today, for example, we recognize that the inert gases of the atmosphere — helium, neon, argon, krypton, and xenon — are so much alike chemically that it is difficult to separate them. These elements had not been discovered in Newlands' time, but he observed other families with similar characteristics. For example, the *alkali group* consists of lithium, sodium, potassium, rubidium, and cesium, all very active metals with a combining power of one. Another such family is the *alkaline earth group*, consisting of magnesium, calcium, strontium, and barium, which are metals which occur in similar types of compounds and exhibit a combining power of two. The *halogens* are a group of very active nonmetals with a combining power of one. This group consists of fluorine, chlorine, bromine, and iodine. Newlands arranged the elements in the increasing order of their atomic weights and observed that every eighth element seemed to belong to the same

family. As Newlands expressed it, "the eighth element starting from a given one is a kind of repetition of the first, like the eighth note of an octave of music."

Independently of each other and in ignorance of Newlands' work, *Lothar Meyer* in Germany and *Dmitri Ivanovitch Mendeléeff* in Russia made a thorough study of the properties of the elements and noted a similar relationship. They proposed the law, known as the *periodic law*, which states that *the properties of the elements are periodic functions of their atomic weights*.

Periodicity is very common in nature. The growth of trees, the cycle of droughts, periods of large sunspots, the tides, and the full moon all occur periodically. A flattened wheel on a railroad car produces a periodic clatter which is a function of the distance traveled, because every full turn of the wheel brings the flattened portion of the wheel into contact with the track.

Mendeléeff prepared a table of the elements based upon their periodicity in properties. He left a number of gaps in this table in places where the progression in properties seemed to demand it, arguing that there must be elements which had not yet been discovered. The known character of the elements above and below these gaps made it possible to predict the properties of the missing elements. Mendeléeff made these predictions in 1870 for three elements, calling them *eka-boron*, *eka-aluminum*, and *eka-silicon*. These elements, discovered in 1879, 1875, and 1886, and named scandium, gallium, and germanium, showed properties that checked remarkably closely with those predicted by Mendeléeff. This strong support of the periodic law was strengthened later by the discovery of all but two of the remaining missing elements partly through the aid furnished by the periodic table.

The periodic table is one of the most useful generalizations in chemistry, because it is of great value in predicting the properties of elements and in classifying chemical information.

How shall one explain this very remarkable law? One generally expects to find a common origin or a common building material for people, houses, or materials which are similar in properties. It is the fact that houses are made of smaller units, such as bricks, that makes possible such a wide variety of patterns. This complexity of structure also makes it possible to build large or small houses of the same design, using different numbers of bricks. If the atoms of the elements are ultimate, no relationships should exist. The chief significance of the periodic law is that it suggests the existence of atoms of similar, and therefore complex, structure.

Discharge-tube Experiments Suggested the Electrical Nature of Atoms.

It was observed that the electrons produced in discharge tubes have the same charge and mass, regardless of the nature of the metals used for the electrodes or of the nature of the gas in the tube. It was also observed that a stream of positively charged particles, the canal rays, was produced in discharge tubes in addition to the cathode rays. *Sir J. J. Thomson* developed the hypothesis that the atoms of all the elements are composed of these positively charged particles in combination with electrons.

This evidence of the electrical nature of atoms, furnished by the discharge tube, was confirmed by other observations. The emission of electrons by certain metals when they are heated or exposed to light, the production of an electromotive force by chemical cells or static methods, and Faraday's laws of electrolysis became intelligible with the advent of the electron theory of atomic structure.

The Discovery of Radioactivity Was the Next Major Evidence of the Complexity of Atoms.

The discovery of radioactivity was made in 1896 by *Antoine Henri Becquerel* while he was engaged in the study of the phosphorescence of certain substances. Becquerel selected certain compounds of uranium for the experiments because they are very phosphorescent. The thought occurred to him that uranium compounds might emit X rays, so he exposed a uranium compound to sunlight and placed it above a metal cross which rested on a photographic plate wrapped in a piece of heavy black paper. With the development of the plate the image of the cross became visible, thus showing that a penetrating radiation had been emitted by the uranium.

Becquerel continued his study of this interesting phenomenon and, by a lucky accident, made one of the most momentous discoveries of physical science. He had placed his photographic plate in a dark cupboard with some uranium salt until he could find time on a sunny day to carry out some more experiments. Nearly a month went by before he got around to further work on this problem. It occurred to him to develop the plate and see if it had been affected by the unexposed uranium. This he did, and the plate had been affected; here was a substance that emitted penetrating rays without any excitation.

Pierre Curie (1859–1906) and his Polish wife, *Madame Marie Curie*, became interested in these *Becquerel rays* and started an investigation to learn whether or not there were other substances besides uranium salts that would emit these rays. They discovered that uranium ore, pitchblende, showed this property of emitting rays even more than

the uranium extracted from it. After laboriously working over about a ton of the rock, they extracted about 0.1 gram of a material that gave radiations several thousand times as intense as those emitted by uranium salts. After the death of her husband, Madame Curie obtained in 1910 a metallic element from their material and gave the new element the appropriate name *radium*. The *property of emitting radiations shown by uranium, radium, and various other elements is called **radioactivity**.*

In addition to uranium and radium, Madame Marie Curie discovered another radioactive element, polonium; and since that time several others have been identified. It has been found that the radioactivity of some elements persists for a very long time (millions of years), while that of other elements lasts for only a few hours, minutes, seconds, or fractions of seconds. It has also been found that as the radioactivity of an element decreases, new elements appear. In 1903 *Rutherford* and *Soddy* announced their disintegration hypothesis, which supposed that masses composed of large numbers of atoms of radioactive elements gradually disintegrate to produce atoms of different atomic characteristics or of a different element, somewhat as popcorn pops in a popper. There are rays given off in this process which carry enormous quantities of energy.

It was also discovered that three kinds of rays, the alpha, beta, and gamma rays, were emitted, although all three kinds were not emitted by any one element.

Radioactive Rays Resemble Discharge-tube Rays.

Alpha rays are not like true electromagnetic rays such as X rays or other electromagnetic radiations but consist rather of positively charged particles of matter, as is shown by their deflection by magnetic and electrical fields. These alpha particles, as they are called, ionize gases by dislodging electrons from the molecules with which they collide. The formation of these ions can be demonstrated by causing the alpha particles to pass through a space that is saturated with water vapor. When the moist air is expanded under suitable conditions, the ions produced act as nuclei for the condensation of small droplets of water, which may then be photographed. When alpha particles strike a screen painted with zinc sulfide, tiny flashes of light are produced. This furnishes a method of counting alpha particles. By means of such a device, called a *spinthariscope*, and by means of alpha-particle tracks in a cloud chamber, we become witnesses of the effects produced by single individual atoms, and our belief in the atomic theory is thereby strengthened. The total charge of a number of alpha particles may

be determined, and this, divided by the number of alpha particles present, gives the charge of one alpha particle. This charge is twice that of a single hydrogen ion. The hydrogen ion is the positively charged nucleus of a hydrogen atom, resulting from the loss of an electron.

The mass of the alpha particle has been found to be four times the mass of the hydrogen ion. Inasmuch as the mass of an atom of helium is also four times the mass of a hydrogen atom, it looked as though alpha particles are helium atoms which bear a positive charge. *Rutherford* showed definitely that these alpha particles are charged helium atoms when he produced a helium spectrum with the gas in a tube, which did not previously give this spectrum, by merely passing alpha particles into it.

Beta rays have the properties of streams of electrons moving with high velocities. Thus alpha rays resemble the positive rays in a discharge tube, while beta rays resemble the cathode rays in the discharge tube. The third ray, the gamma ray, resembles the X ray very much in its effect on photographic plates, in producing chemical changes, and in therapeutic properties. Gamma rays differ from X rays only in energy content and, of course, source.

The Discovery of Radioactivity Was Epoch-making.

The discovery of radioactivity provided the final evidence for the complexity of atoms, thus making it necessary to discard the idea that atoms are ultimate units of matter. It gave evidence that the atoms of all elements are made up of positively charged hydrogen atoms (protons) and electrons and thus showed that Prout's ideas were remarkably near the truth. It showed that elements may decompose to form lighter elements, thus suggesting that the quest of the alchemists was not as hopeless as chemists of the nineteenth century had thought. In 1912, *J. J. Thomson* found two kinds of neon, of atomic weight 20 and 22, respectively. Later it was discovered that the atomic weight of lead produced by the decomposition of radium was less than that of ordinary lead. These discoveries thus led to the idea that there could be several kinds of atoms of the same element, similar in chemical properties but differing in atomic weight. Such elements are called *isotopes* and explain why the atomic weights of some elements are apparently not whole numbers.

The Positive Charges of Atoms Are Concentrated in a Nucleus.

Electrons and alpha particles may be shot through thin sheets of glass or metal containing thousands of layers of atoms very close together. The only way we can account for this fact is by assuming

that atoms have an open structure similar to that of our solar system. Each atom is then considered to consist almost entirely of unoccupied space, which electrons or alpha particles could pass through without hitting anything, just as the stars move rapidly through space for millions of years without meeting another star.

Ernest Rutherford found that the majority of alpha particles would pass through very thin metal foils without changing their direction, but that some alpha particles would be more or less deflected, while others would rebound from the foil. A relatively heavy mass, positively charged, must have caused these deflections in direction. *Rutherford* calculated that all of the positive charges in a gold atom must be concentrated into a space having a diameter of about one hundred-thousandth that of the whole atom in order to produce the deflection which he observed. *Rutherford* therefore concluded that atoms are composed of a very small positively charged nucleus surrounded by electrons distributed at intervals throughout the rest of the space within the atom. The atom is, therefore, not a solid unit of matter but a portion of space in which the nucleus maintains its attraction for a number of electrons equal to the charge on the nucleus.

Moseley Affixed the Atomic Numbers of the Elements.

Sir W. H. Bragg found that the surface of a crystal could be used to reflect X rays. The X rays produced when cathode rays in a vacuum tube strike any target are composed of radiations of many different frequencies. These rays are diffracted, or sorted out, by the crystal, in much the same way that a prism or diffraction grating sorts out visible light into its component colors.

H. G. J. Moseley found that in passing from one element to another in the periodic table all of the lines in the X-ray spectrum are shifted. Thus it became possible to determine the position of an element in the periodic table by measuring the shift in the X-ray spectrum. Starting with hydrogen, the elements are numbered according to this shift, and the number so obtained is called the atomic number.

Moseley's atomic numbers were obtained by experiment and in themselves gave no definite information concerning the internal structure of atoms.

The Mass Spectrograph Revealed the Existence of Many Isotopes.

F. W. Aston (1877-   ), of the Cavendish Laboratory in England, modified and greatly improved Thomson's original mass spectograph. With the mass spectograph one may determine the atomic weights of the elements. One half of the elements have had their atomic weights

determined by this method, which has been found to give values agreeing with those obtained by chemical means within 1 part to 1000 or better.

The mass spectrograph showed that many of the elements have atomic weights which are the mean of the atomic weights of two or more isotopes. (*Isotopes are atoms having different atomic weights but the same atomic number.*) The existence of these isotopes is best shown by the mass spectograph, but there is other evidence for their existence, as explained in the next paragraph.

The Majority of the Elements Are Mixtures of Isotopes.

We have already mentioned the fact that the different atoms of an element are not always of the same weight but that most elements are composed of atoms of two or more different weights, having the same atomic number. The chief characteristic of an element, therefore, is its atomic number. The reason that the chemical atomic weight of most elements is the same, regardless of their source, is that these isotopes are intermingled in nature in very nearly constant proportions.

It was found that forty or more different kinds of atoms were produced by radioactive decomposition of natural radioactive elements and that in many cases these different kinds of atoms showed the same chemical properties and were therefore atoms of the same element. For example, it was found that lead (average atomic weight = 207.2), with atomic weights of 214, 212, 210, 208, 206, and 204, was obtained by the decomposition of uranium, thorium, and protoactinium.

The discovery of the existence of isotopes naturally led chemists to try to separate possible isotopes of nonradioactive elements by chemical or physical means. Such attempts met with considerable success. For example, isotopes of chlorine were partially separated by *Harkins* and his co-workers by use of diffusion methods.

In 1932 an isotope of hydrogen with the atomic weight of 2 was discovered by *Harold C. Urey* and his co-workers by examining spectroscopically the least volatile portion of some liquid hydrogen which had been subjected to fractional distillation. This new hydrogen is called deuterium, and water prepared from it is called deuterium oxide, or *heavy water*. Deuterium is now separated by electrolysis, fractional distillation of water, and other methods. There is about one part of deuterium in 6000 parts of ordinary hydrogen. The discovery of deuterium made possible some recent great advances in the transmutation of elements.

In 1940 heavy sulfur, atomic weight 34, as compared with ordinary sulfur of atomic weight 32.06, was separated by Urey and his workers

at a cost of about $400 per ounce; and heavy carbon, atomic weight 13, as compared with ordinary carbon of atomic weight 12, was made available at $400 per ounce. Nitrogen of atomic weight 15 was first separated in 1937. It may now be obtained at about the same cost as that of carbon of atomic weight 13.

Nonradioactive Elements Have Been Disintegrated by Bombardment with High-speed Particles.

In 1919 *Ernest Rutherford* was able to produce protons by the bombardment of nitrogen atoms with alpha particles. Later he found that when bombarded by alpha particles, the nuclei of some other elements would emit protons, while those of certain others would not.

Since 1930 it has been observed that very penetrating radiations are produced when alpha particles from radioactive elements, such as polonium, fall upon beryllium or boron. In 1932 *Chadwick* showed that this radiation consists of particles of about the same mass as protons but having no charge. He called these particles *neutrons*. The neutron's mass corresponds to that of ordinary hydrogen (now sometimes called *protium*). The neutron thus corresponds to an element with an atomic number of zero.

E. O. Lawrence and *M. Stanley Livingston*, of the University of California, have produced rays consisting of a stream of about 10,000,000 neutrons per second, produced by bombardment of beryllium with high-speed deuterons. (Deuterons are the positively charged nuclei of deuterium.) These rays are found to be more penetrating than X rays or gamma rays and will destroy both plant and animal life.

In 1932 *Carl D. Anderson*, of the California Institute of Technology, announced the discovery of a positive electron, now called the *positron*. This particle has the same mass as the negative electron — *i.e.*, 1/1845 the mass of the proton — but its charge is positive rather than negative.

In 1937 physicists studying cosmic rays discovered the *mesotron* (heavy electron), which is 150–180 times as heavy as the electron but has the same charge as an electron.

Since 1931 swiftly moving protons, accelerated by traversing electrical fields of high potential differences, have replaced alpha particles as projectiles. Since 1932 deuterons and neutrons have also been employed as projectiles. With these projectiles a great many interesting transformations have been accomplished; thus, lithium has been converted into helium, and a large number of other nuclear reactions have been brought about. About sixty elements have been transmuted by means of the neutron. The significance of all these trans-

mutation experiments is that they show that *all of the elements are composed of the same material.*

In 1940 element 93 of atomic weight 239 was identified. It was produced by bombarding uranium, element 92, of atomic weight 238, with neutrons; thus an element heavier than any previously known element was produced. Since that time *E. Fermi* and his co-workers have similarly produced elements 94 and 95.

In 1940 plans were made by *E. O. Lawrence* to build a powerful cyclotron, dwarfing all others by three times in linear dimensions, whose huge electromagnet alone would weigh about 4000 tons; 300 tons of copper will be used in the windings.

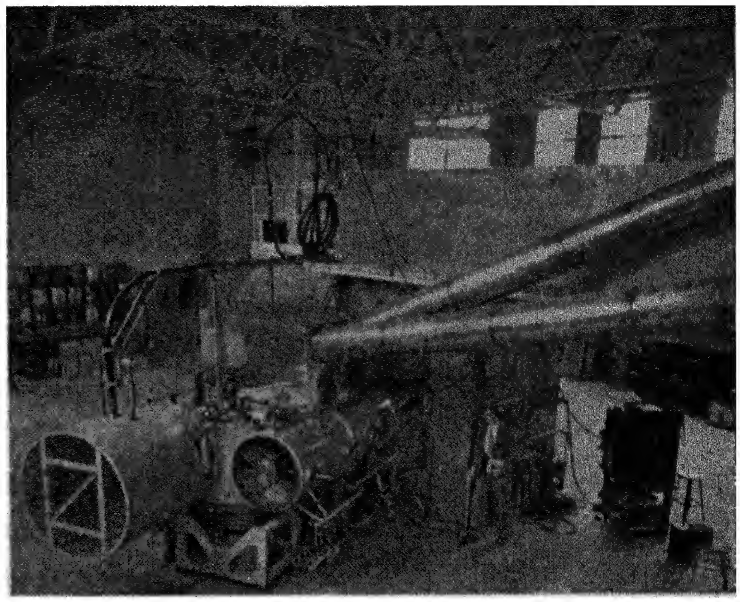


FIG. 275. The 200-ton cyclotron at the University of California produces atomic particles with energies as great as 32,000,000 electric volts. (Courtesy of Ernest O. Lawrence.)

Artificial Radioactivity Is Now a Reality.

In 1934 *Madame Irene Curie-Joliot*, the daughter of *Madame Marie Curie*, and her husband, *F. Joliot*, discovered that ordinary inactive elements such as aluminum, boron, and magnesium, when bombarded with alpha rays, were transformed into substances which exhibited radioactivity for varying periods of time after the bombardment ceased.

Since that time other workers have produced artificial or induced radioactivity by use of protons, deuterons, and neutrons as projectiles. *Ernest O. Lawrence*, at the University of California, has produced radioactive sodium. It is

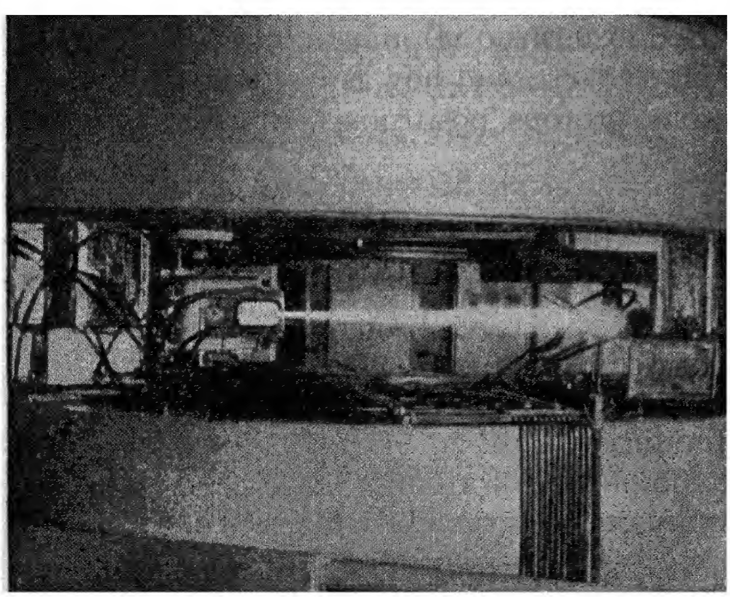


FIG. 276. A beam of deuterons with an energy of 16,000,000 electron volts, produced by the University of California 200-ton cyclotron. (Courtesy of Ernest O. Lawrence.)

quite probable that radioactive sodium will soon be produced in sufficiently large quantities to make it possible for use in replacing radium for many purposes. This radioactive sodium has a half-life [1] of only fourteen hours, but it could be produced when needed. Radioactive carbon has also been produced.

In 1937 *E. Fermi* showed that neutrons slowed to velocities of atoms of hydrogen at ordinary temperatures are very effective in producing radioactive substances.

In 1940 radioactivity was induced in uranium 235. In 1939 it was shown that uranium atoms when bombarded with neutrons disintegrated into nearly equal atomic fragments with the liberation of enormous energies instead of inducing the emission of electrons, protons, or helium nuclei as usually occurs. In this splitting or fission, neutrons are produced which can react with other uranium nuclei and thus continue the process. In all previous experiments in which radioactive substances had been produced, the radioactivity gradually decreased, but here for the first time self-regenerating radioactivity had been induced. At last a new source of power, that bound up with the atom, has been tapped, although its practical application is still a dream. The reason that uranium 235 may be a source of power is that for each disintegration about 200,000,000 electron-volts of energy are given out.

STUDY QUESTIONS

1. How do you account for the fact that electrons and alpha particles may be shot through thin sheets of glass or metal containing thousands of layers of atoms very close together?
2. Summarize the present thoughts concerning the nature of atomic nuclei.
3. Why is the periodic law best stated in terms of atomic numbers?
4. What is the atomic number of an element, and how is it obtained?
5. Compare atoms, neutrons, electrons, protons, positrons, deuterons, and alpha particles as to mass, charge, and size.
6. Define isotope.
7. Why are the atomic weights of certain elements not whole numbers, while the atomic weights of quite a number of elements are very nearly whole numbers?
8. What is deuterium, and how may it be obtained?
9. What is "heavy water"?
10. How is artificial radioactivity produced?
11. Summarize the evidence of the complexity of atoms.
12. State the periodic law, and show by one or more illustrations what it means.
13. What is meant by *radioactivity?*
14. Compare the radiations emitted by radioactive substances with the rays produced in discharge tubes.
15. What new ideas resulted from the discoveries of radioactivity?

[1] Half-life is the time required for one half of any weight of a radioactive element to disintegrate.

UNIT VIII

SECTION 4

MOLECULES ARE HELD TOGETHER BY ELECTRICAL OR MAGNETIC ATTRACTION OF ATOMS

Introduction.

Chemical changes represent rearrangements of atoms within molecules or the decomposition or combination of molecules to form smaller or larger molecules containing fewer or more atoms. What force holds atoms together within molecules? Are these forces the same for all atoms? By what means may these forces be overcome to bring about new arrangements of atoms within molecules? These are the questions which have puzzled chemists for many years. Some of them can now be answered, although the answers are very incomplete.

Chemical Affinity Was First Used to Explain the Attraction between Atoms.

In the thirteenth century, the Dominican monk, *Albertus Magnus*, used the word "affinitas," which expressed the idea that only atoms having a similarity or kinship would unite to form molecules. The Greek philosopher, *Hippocrates*, expressed the same idea when he maintained that "like unites only with like." In the eighteenth century *Boerhaave* and others arrived at the opposite conclusion, namely, that dissimilar atoms show the greatest tendency to combine.

Before the knowledge of electricity developed, the nature of this force of affinity was not known. The terms "love" and "hate" were often used for want of anything better. It was known, however, that the affinity between the various atoms differed, and many attempts were made to arrange the elements in the order of their affinity for other elements. Today it is believed that chemical affinity is a force, electrical in nature, which acts between the different kinds of atoms to bring about chemical changes.

The Properties of the Elements Depend upon Their Structures.

Some metals are good conductors of electricity; others are not. Some metals may be pulled out to form fibers smaller in diameter than

that of spider-web filaments; other metals crumble readily. What causes these differences in the properties of the elements? According to the present theory of atomic structure, the differences in the properties of the elements are explained in terms of the differences in the number of electrons in the outermost levels of the atoms.

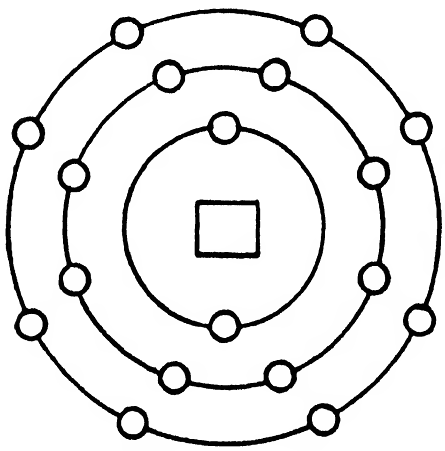


FIG. 277. The argon atom has eight electrons in the outer layer. It does not react with other elements.

When there are eight electrons in the outermost level, the atoms show no attraction for each other and refuse to combine with other atoms of the same kind or with atoms of different elements. The elements helium, neon, argon, krypton, xenon, and radon are all gases; even the very heavy element radon is a gas; and these gases consist of molecules which have only *one* atom to the molecule.

In contrast with the rare gases, carbon and silicon form by far the largest number of the known compounds of the elements. These atoms are assumed to have four electrons in the outer level, and because of this fact they are the most gregarious of all the elements. Four carbon atoms may cooperate, each sharing one of its outside electrons with one carbon atom, producing an arrangement somewhat similar to the one shown in Fig. 279. By cooperating, each atom is given a stable configuration. In the diamond, which is pure carbon, we see how well the carbon atoms have joined each other to form a very hard, compact, inert material.

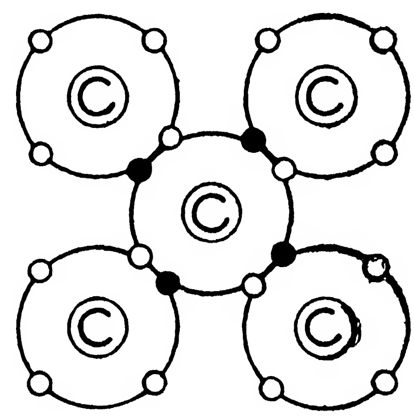


FIG. 278. Carbon atoms share pairs of electrons.

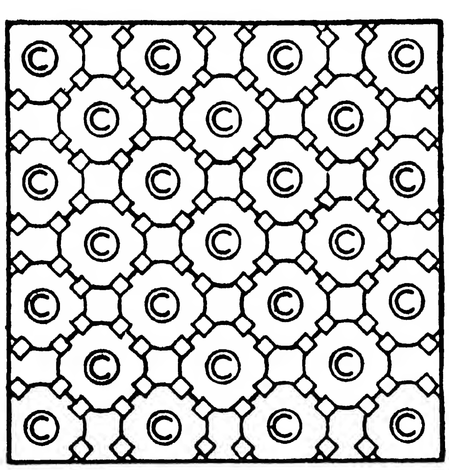


FIG. 279. The carbon atoms in the diamond are arranged very compactly.

Silicon has an outside structure similar to that of carbon and likewise forms hard crystals. Silicon will also combine with carbon to form the beautiful, very hard crystals of carborundum.

Silver has only one electron in the outermost level. Seven other silver atoms would have to share their electrons to enable one silver atom to fill its level with eight electrons, but in the meantime each of these

seven other atoms would require still seven other atoms to complete their outer levels. It is thus apparent that there are not sufficient electrons to form a stable arrangement. Each atom has an attraction for other atoms, but there are fewer electrons to hold them together. Therefore such elements as sodium, copper, and silver are quite soft and conduct electricity readily because electrons are free to pass from one atom to another. Such metals can be pounded into very thin sheets and will combine readily with any element which has a greater affinity for electrons. A piece of hot copper foil, when placed in chlorine gas, bursts into flame because of the greediness of chlorine for electrons; inasmuch as each chlorine atom has seven electrons in its outer level, it needs and takes an electron from the copper atom in order to obtain the stable arrangement of eight electrons in the outer level.

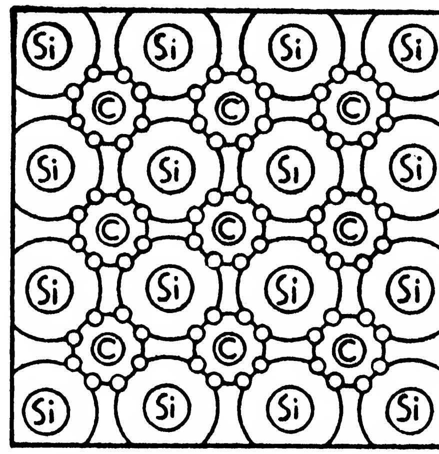


FIG. 280. Each silicon atom is surrounded by four carbon atoms in carborundum. This is a stable arrangement.

Metals like magnesium, which have two outer electrons, and aluminum and iron, which have three outer electrons, show increasing hardness and decreasing electrical conductivity.

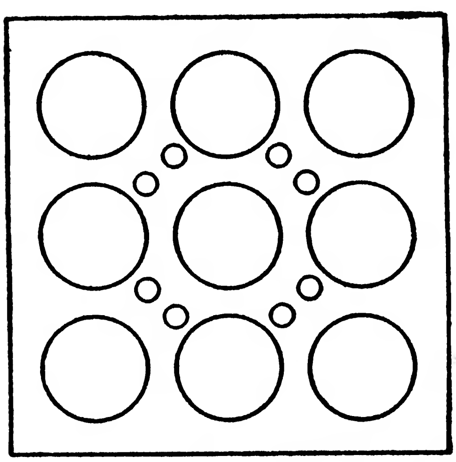


FIG. 281. There are too few electrons to keep these metallic atoms in a rigid position. The electrons are mobile.

Nonmetals like nitrogen, oxygen, and chlorine, which have five, six, and seven electrons, respectively, in their outer levels, have too many electrons to form large stable groupings and exist as gases, containing only two atoms to the molecule.

Space will not permit further *speculations* concerning the electrical forces which hold atoms together, but one can be sure that the properties of the elements are the result of their structures; no theory of atomic structure will be satisfactory that does not explain these properties.

Atoms Differ in Their Combining Capacities.

Valence represents *the number of atoms of a standard univalent element (hydrogen) that will combine with or are equivalent to one atom of a given element.* Thus the valence of oxygen is 2 because it combines with two atoms of hydrogen to form water, H_2O. The valence of

aluminum is 3 because two atoms of aluminum combine with three atoms of oxygen, each of which has a valence of 2, to form aluminum oxide, Al_2O_3 ($2 \times 3 = 6$, $3 \times 2 = 6$).

It has been found that the maximum valence exhibited by any element is 8. It was also observed early in the history of modern chemistry that atoms of metals have a greater tendency to react with atoms of nonmetals than with atoms of other metals. It was only natural for the expression *metallic* and *nonmetallic* valence to come into general use. Later these expressions were changed to *positive* (+) and *negative* (−) valence, respectively. The general conclusion was thus reached that molecules are formed by the combination of atoms of positive valence with atoms of negative valence and that the valence of each atom must be completely satisfied in each reaction.

Valence Is Now Believed to Represent the Number of Electrons Gained or Lost or the Number of Pairs of Electrons Shared in Chemical Reactions.

Knowledge of the structure of atoms made possible the electron theory of valence. According to this theory, the reactions between atoms are governed by the number of electrons in the outermost levels or orbits of the atoms. In certain types of reactions the atoms of metals give up all of their outside electrons to the atoms of nonmetals, and the nonmetals annex enough electrons to make the sum of eight in their outermost orbits. As the result of this loss of electrons by the metals to become positively charged and the gain of electrons by the nonmetals to become negatively charged, the metals and nonmetals are attracted to each other to form compounds. Such changes are called *electrovalent* reactions, the compounds produced are called *electrovalent* compounds, and the valence represented by the gain or loss of electrons is called *electrovalence*.

Some atoms exhibit two, three, or more valences. This is explained by assuming that in these atoms the number of electrons in the outside orbit differs in each case, as the result of one or more of the electrons moving from the outside orbit to an inner orbit or vice versa. Obviously, energy is used up in changing the orbits of these electrons.

Various factors influence the tendency of elements to gain or lose electrons. Elements which have fewer than four electrons in the outer orbit tend to lose their electrons and thus become positively charged. Such elements are said to have a metallic, or positive, valence. Elements which have four electrons in the outer orbit tend either to lose or to gain these electrons and may thus act as metals or nonmetals. Elements having more than four electrons in the outer

orbit tend to gain electrons and are said to exhibit a nonmetallic, or negative, valence.

The larger atoms show a greater tendency to lose electrons, inasmuch as the outer electrons are held less firmly because of the greater distance that separates them from the nucleus. Atoms of light nonmetals tend to gain electrons more readily than heavy nonmetallic atoms for the same reason.

In many chemical reactions there is no gain or loss but rather a sharing of electrons. The compounds thus produced are called *covalent* compounds, and the valence represented is called *covalence.* Molecules of elements, for example, are *covalent* in nature.

All Chemical Reactions Are Accompanied by Energy Changes.

Inasmuch as the energy which holds the atoms together in molecules differs in each compound, every chemical reaction involves either an absorption or evolution of energy. In some cases the energy evolved may be in the form of electrical energy, as in the case of chemical cells. In other cases the energy is evolved as light, but in the majority of cases it is evolved as heat. All reactions in which heat is evolved are called *exothermic*, and those reactions which absorb heat are called *endothermic.* It is a matter of conjecture as to the actual causes of this absorption or evolution of energy in chemical reactions, but it is certain that the explanation will be based on the study of atomic structures.

Electrovalent Reactions Do Not Need to Be Activated, but Covalent Reactions Require Activation.

In the case of reactions between electrovalent compounds, there is simply a new combination of charged atoms. These charged atoms, or *ions*, as they are called, must be separated from each other before they can combine in new ways. In order to free the ions in electrovalent compounds, it is only necessary to dissolve them in a solvent which acts as an electrical insulator in so far as the ions are concerned. By evaporating the solvent, the ions combine once more. If any two or more ions may combine in such a way as to be removed from such a solution, they will do so, and thus new compounds are formed; for example, it will be shown in a later section that ions may be removed from solution by forming insoluble solid or gaseous compounds.

In the case of covalent compounds, however, it is difficult to bring about recombination of the atoms to form new molecules. In general, it is thought that molecules must collide with each other in order to react, and that these collisions produce no chemical reactions except

in cases where at least one of the molecules has been *activated.* Ions may be regarded as activated molecules which combine immediately upon contact. As we have pointed out above, the conditions determine whether these ions will remain combined or separate again at once. The activation of covalent molecules is thought to consist of the addition of an unusual amount of energy to the molecule. This may be accomplished by collision with photons of radiant energy or with swiftly moving electrons, atoms, molecules, or ions. The energy thus added produces an increase in kinetic energy, a displacement of electrons from relatively stable orbits to less stable orbits, an increased energy of vibration of the atoms within the molecules, or an increased energy of rotation of the whole molecules.

This added energy may be emitted in the form of radiant energy as fluorescence or phosphorescence as the electrons return to their more stable orbits. In other cases this energy of activation is removed by collision with other particles, thus increasing their kinetic energy; this represents an increase in temperature. The energy represented by the vibration of the atoms may be transmitted from atom to atom within the molecule until it reaches a weak or ruptured bond, when the molecule is either decomposed or internally rearranged. Sometimes activated molecules lose their extra energy by direct union with other molecules; in such cases energy is released. This released energy then activates other molecules, producing what is known as a *chain reaction.* In case the amount of energy released is greater than that required for activation, the reaction will be *exothermic.* On the other hand, the amount of energy evolved may be less than that required for activation, and the reaction can be made to continue only by adding sufficient energy to activate the reacting molecules. Such reactions are *endothermic.*

In the explosion of an explosive mixture of gases, an electric spark furnishes all of the energy necessary to activate a few molecules. These activated molecules react to produce sufficient energy to activate many more molecules, and so the reaction proceeds. Explosions are typical chain reactions. In the starting of a fire, the heat of a burning match is sufficient to activate a few molecules; these, in turn, activate many more molecules; soon a whole city or forest may burn up unless the reaction can be stopped. The usual method of stopping such reactions is by pouring on water, which uses up the energy evolved by the reactions as the water is heated and finally vaporized.

On the other hand, it is necessary to keep on adding energy when one chars some sugar or bakes a cake because the changes in this case are endothermic.

Photography Is an Application of the Activation of Atoms by Radiant Energy.

The development of photography has been of inestimable value to Science and modern life. For example, the scientist has used photography to study the internal structure of the atoms, the nature of far-distant nebulae, flaws in metals, and in the diagnosis of disease by use of X rays. Photography has made possible our modern illustrated books, newspapers, and magazines, and the motion-picture industry. It is only necessary to compare silent motion pictures made twenty years ago with the modern sound motion pictures in color to realize the tremendous progress that has been made in photography during the past generation.

It was known for a long time (*J. H. Schulze*, 1727) that light would blacken silver nitrate or silver chloride, but for practical purposes early photography had two great drawbacks: first, no means of fixing the images were known; second, time required for the exposures was quite long. *Louis Jacques Daguerre*, in 1839, made public the details of his *daguerreotype* process of sensitizing a silver plate with iodine and developing with mercury vapor. *Fox Talbot* (1835) found that if he treated paper with successive washings of a solution of common salt (sodium chloride) and a solution of silver nitrate and exposed the wet paper, he could obtain a much more rapid blackening in light than with either silver nitrate or silver chloride alone.

Unfortunately the silver chloride left on the paper unchanged by the light will soon darken unless removed, and such a picture will soon become black all over when exposed to light.

Later it was found that a silver-salt emulsion could be exposed to light without producing any visible change but that the portion of the salt thus activated, even after a period of thirty or more years, would be reduced by certain substances which develop this *latent image* and are therefore called *developers;* the portions of the emulsion not activated are not appreciably reduced during the short period of time required to reduce the activated portion, but continued exposure to the developer would eventually reduce nearly all of the silver salts in the emulsion. *Fox Talbot* discovered the use of a developer (gallic acid) and reported it to the Royal Society in 1841. The most common developers are pyrogallic acid, hydroquinone, and methyl-para-amino-phenol sulfate, otherwise known as "Pictol," "Metol," or "Elon."

It was found that larger crystalline particles were more readily activated than the smaller particles and that the sensitiveness to light could also be controlled by the use of the bromide and iodide of silver, as well as the chloride. Silver bromide is more sensitive to light than

silver chloride. A mixture of the bromide and iodide (within certain limits) is more sensitive than either the pure bromide or iodide. Photographic films which are very sensitive to light are called *fast* films because they can be used with a *fast* shutter speed (short exposure). A *slow* film, on the other hand, requires long exposures. Suspensions of these salts in specially prepared gelatine may be made extremely sensitive to infrared, ultraviolet, and other portions of the electromagnetic spectrum by the addition of special sensitizing agents and by heat treatment of the emulsion. One of the first observations which led to the modern sensitized films was based on the fact that films whose emulsion contained gelatine made from cows which had been eating plants containing mustard oil were unusually sensitive. This observation led to the use of mustard oil (allyl isothiocyanate) to sensitize emulsions. The emulsion may be coated on celluloid or cellulose nitrate or acetate film bases, glass plates, or paper.

After exposure to light, the film or plate is placed in the developing bath, which contains one or more of a number of substances which will reduce the exposed areas, liberating free silver from its salts. The size of the silver particles and other factors determine the *grain*, which is very important in enlarging. Developers which produce very small free silver particles are called *fine-grain developers*. The speed and contrast in developing are controlled by the use of substances such as sodium carbonate (the accelerator), to provide an alkaline solution, and potassium bromide (the restrainer), which helps to prevent reduction of the unactivated silver salts. Sodium sulfite (the preservative) is also added to the developing solution to prevent deterioration due to the action of the reducing agent with the oxygen of the air.

The unexposed compounds remain unchanged after the reduction of the exposed portion. These unchanged compounds would also be reduced if left exposed to the light, so they are treated with "hypo" (sodium thiosulfate) in the fixing bath, which dissolves these unreduced silver salts. An acid is generally added to the fixing bath to stop the action of the developer because it neutralizes the alkali which is essential to the action of the developer. Potassium or chrome alum is added to harden the gelatine of the emulsion, which is softened and swollen by the sodium carbonate or other alkaline substance in the developing solution. Sodium sulfite is also added to oppose the decomposition of the "hypo."

Ordinary films and plates when developed are called negatives. Negatives represent the reverse of the light values of the original subject. By passing light through a negative held in contact with a paper, film, or plate coated with photographic emulsion, the tone

values are again reversed. This operation is called *contact printing*. If a lens is placed between the negative and the photographic printing paper, an enlarged or reduced image is obtained. A device which makes it possible to vary the size of the image produced by changing the relative distance between the lens, the negative, and the unexposed emulsion surface is called an *enlarger*. The process of developing and fixing the paper, film, or plate which has been exposed by contact or in an enlarger will produce a faithful reproduction of the original subject.

Amateur motion-picture films do not need to be printed, the original film being treated by a reversal process of developing which produces a positive rather than a negative. In addition to processes of developing and fixing, there are the processes of toning, in which the black silver is changed to a salt of another color, and the processes of reduction and intensification, which are used to correct under- and overexposed negatives.

STUDY QUESTIONS

1. What is meant by valence? What rule of valence must be observed in writing formulas of compounds?
2. How do you account for positive and negative valence?
3. Define metals and nonmetals in terms of their tendency to gain or lose electrons.
4. Compare electrovalent reactions with covalent reactions.
5. What are ions, and how are they formed?
6. Why are free ions not found when electrovalent compounds are dissolved in some solvents, while they are found in solution in certain other solvents, such as water?
7. Outline the main principles of photography.
8. Why is activation important for covalent compounds?
9. What type of compound is largely covalent in nature?
10. How may molecules be activated?
11. Explain the difference between exothermic and endothermic compounds.
12. Why do endothermic reactions require a continual supply of heat to keep them acting?
13. What is meant by developing a photographic film?
14. What is the purpose of fixing a photographic film?
15. What is the basic principle of photography?

UNIT VIII

SECTION 5

ELECTROVALENT REACTIONS CONSIST OF REACTIONS BETWEEN IONS

Introduction.

In the last Section it was pointed out that many reactions are electrovalent in nature and that electrovalent compounds are held together by the attraction of oppositely charged ions. What evidence is there for the existence of ions? Why do some substances ionize while others do not? Such questions will be considered in this Section, as we consider one of the greatest and, incidentally, one of the most incomplete and least satisfactory theories of physical science — namely, the theory of electrolytic dissociation.

The Theory of Electrolytic Dissociation Explains Many Phenomena.

1. The Irregularities of Solutions of Electrovalent Compounds. In the study of the properties of solutions it is observed that electrovalent compounds show abnormal behavior; for example, it is readily shown that for solutions of equal numbers of molecules of solute in a given amount of solvent, the freezing-point lowering is greater, the boiling-point elevation is greater, and the lowering in vapor pressure is greater in the case of polar compounds than in the case of covalent compounds. It may also be observed that the osmotic pressures of solutions of electrovalent compounds are always higher than the osmotic pressures of solutions of covalent compounds of equivalent concentration.

If Avogadro's law can be extended to solutions, these abnormalities of solutions of electrovalent compounds must be ascribed to there being more particles present than in solutions of covalent compounds of the equivalent concentration, because all of these properties are a function of the *number* of particles present rather than of their *nature.* If more particles are present, they must be produced by the dissociation (splitting) of molecules.

It may be observed that reactions between solutions of electrovalent compounds take place almost instantaneously, whereas reactions be-

tween covalent compounds are relatively slow. This difference in the rates of reaction of electrovalent and covalent compounds is explained nicely by assuming that in the case of electrovalent compounds the molecules have already dissociated to form smaller particles and the reaction is simply a joining together of the particles, whereas in the case of covalent compounds the molecules must be broken up into smaller units before reactions can take place and they must come together in a special way.

2. The Phenomena of Electrolysis. Electrovalent compounds, such as acids, bases, and salts, when dissolved in water or in a limited number of other solvents, form solutions which will conduct the electric current; solutions of nonelectrolytes will not conduct the electric current. Electrovalent compounds are therefore called *electrolytes* because their water solutions will conduct an electric current; and covalent compounds are called *nonelectrolytes* because their water solutions will not conduct an electric current. Chemical changes always accompany the passage of an electric current through a solution, and the process is called *electrolysis*.

In 1807 *Sir Humphry Davy* carried out some of the first of the recorded experiments with electrolysis, in which he separated sodium and potassium from their salts. His experiments led to the added information that molten electrolytes, as well as their solutions, will conduct the electric current and be chemically altered. Later investigations showed that hydrogen or a metal separates at the negative electrode (or *cathode*), while a nonmetal, such as oxygen, chlorine, or iodine, separates at the positive electrode (or *anode*).

Michael Faraday discovered a fundamental relation between the quantity of electricity used and the amounts of substances liberated at the electrodes. He found that *the quantities of substances set free at the electrodes are proportional to the amount of electricity passed and that the same amount of current liberates chemically equivalent weights of different substances*. In other words, the amount of electricity necessary to set free a gram-molecular weight of an element is proportional to its valence. Faraday's laws were of great significance in that they showed that the ordinary chemical equivalent weights are *also* electrical equivalents. Thus chemistry and electricity were shown to be very closely allied.

The Theory of Electrolytic Dissociation Was Formulated by Svante Arrhenius.

In 1887 *Svante Arrhenius* proposed what is known as the *theory of ionization*, or *electrolytic dissociation*. According to his theory, mole-

cules of electrolytes dissociate in water solution to form atoms or groups of atoms which are electrically charged and carry the current in electrolysis. The metallic ions are positively charged, and the nonmetallic ions are negatively charged, the charge on the ion being proportional to its valence.

Electrolytes whose solutions are poor conductors of electricity are called *weak* electrolytes, and those whose solutions are good conductors of electricity are called *strong* electrolytes.

Since Arrhenius' time many observations have been made that can be explained best by assuming that strong electrolytes are completely ionized under all conditions and that weak electrolytes consist of covalent compounds that are in equilibrium with electrovalent modifications of these compounds.

The Theory of Electrolytic Dissociation Explains the Properties of Electrolytes.

1. Properties of Acids, Bases, and Salts Are Due to the Properties of Their Ions. Solutions of acids have only one thing in common, that is, hydronium ions, H_3O^+.[1] It is concluded, therefore, that the properties of acids are due to the hydronium ions present in their solutions. Solutions of those acids which have strongly acid properties have more hydronium ions present in a given volume than do solutions of weak acids.

What has been said of acids applies to bases, except that in this case the characteristic ions are hydroxyl ions, OH^-.

The ionization theory also accounts for the properties of solutions of acid and basic salts, by stating that such salts dissociate to form H_3O^+ ions and OH^- ions, respectively, in addition to the ions of the corresponding normal salts.

2. Precipitation. The formation and separation of an insoluble substance as a product of a chemical reaction is called *precipitation*, the substance thus formed being called a *precipitate*.

Every solid has a definite solubility, and, if the concentration of ions of any substance exceeds that present in a saturated solution, precipitation will take place.

3. Why Reactions Go to Completion. Many reactions do not go to completion; that is, they are reversible. The products of such reactions react with each other to form the original reactants, and before long a condition of equilibrium between the original reaction and the reverse reaction is set up. When such an equilibrium exists, the reactants are

[1] H_3O^+ ions are formed by the combining of protons, H^+, with water, H_2O. Thus:

$$H^+ + H_2O \longrightarrow H_3O^+$$

being formed as rapidly as they are used up, so that for all practical purposes the reaction has ceased.

If one or both of the products of a reaction should be removed, the reverse reaction would be impossible, and the original reaction would go to completion. Inasmuch as chemical reactions between solutions of electrolytes are really reactions between the ions, the problem resolves itself into that of removing one or more of the ions of the reaction products. Ions may be removed from solution in the following ways:

1. By the formation of an insoluble substance.
   a) *By the formation of a precipitate.* If ions combine to form an insoluble solid, it is evident that they are thereby removed from the solution.
   b) *By the formation of a gas.* If ions combine to form an insoluble gas, which bubbles out of the solution, it is evident that they would likewise be removed from the solution.
2. By the formation of slightly ionized soluble substances.
   a) *By the formation of slightly ionized molecules.* The formation of slightly ionized molecules would certainly greatly reduce the concentrations of the ions concerned in the solution, depending upon the apparent degree of ionization of these molecules.
   b) *By the formation of complex ions from simpler ions,* thus removing the simpler ions from solution.

Additional applications of the theory of electrolytic dissociation will be discussed in the next two Sections.

STUDY QUESTIONS

1. Define *electrolyte.*
2. What two types of phenomena does the theory of electrolytic dissociation explain?
3. What types of compounds are electrolytes?
4. Outline briefly the main points of Arrhenius' theory of electrolytic dissociation.
5. How did Arrhenius explain the fact that solutions of some electrolytes conduct the current better than solutions of other electrolytes?
6. What do solutions of all acids have in common?
7. What are the characteristic ions of bases?
8. Give four methods of removing ions from solution.
9. Why do reactions go to completion?
10. Differentiate between strong and weak electrolytes.
11. Define (*a*) acid, (*b*) base, (*c*) salt, (*d*) acid salt, (*e*) basic salt.
12. What is electrolysis?
13. What are the irregularities of solutions of electrolytes?
14. State Faraday's laws.
15. What are ions and how are ions formed?
16. What determines the charge on an ion?
17. Define (*a*) cathode, and (*b*) anode.
18. How would you define cations and anions?
19. Are metallic ions cations or anions?

UNIT VIII

SECTION 6

ATOMS DIFFER IN THEIR TENDENCY TO LOSE ELECTRONS

Introduction.

It is now known that the elements differ in their tendency to release and accept electrons. A very important type of chemical reaction is based on the transfer of electrons from one substance to another. The electrochemical industry, battery action and cell action, the smelting of ores, the corrosion of metals, and many other important types of chemical changes are examples of the transfer of electrons.

Three Types of Chemical Reactions Have Been Recognized.

There are three main types of polar reactions, *proton transfer*, *double decomposition*, and *electron transfer*. Reactions involving *proton transfer* will be discussed in Sections 7 and 8 of this Unit. *Double decomposition* reactions simply involve recombinations of ions in solutions which result from ions being removed from solution by any one of the methods which cause electrovalent reactions to go to completion. Such reactions were discussed on p. 589.

There are four important types of *electron transfer* reactions: (1) *decomposition*, (2) *direct union*, (3) *displacement*, and (4) *oxidation-reduction*.

Decomposition, in general, refers to the breaking-down of one compound to form two or more simpler compounds or elements; for example, mercuric oxide, when heated, gives mercury and oxygen:

$$\underset{\text{mercuric oxide}}{2\,HgO} \longrightarrow \underset{\text{mercury}}{2\,Hg} + \underset{\text{oxygen}}{O_2}$$

Direct union is the opposite of decomposition; for example, iron combines with oxygen in the presence of water to form iron oxide (rust):

$$\underset{\text{iron}}{4\,Fe} + \underset{\text{oxygen}}{3\,O_2} \longrightarrow \underset{\text{iron oxide}}{2\,Fe_2O_3}$$

Displacement is the displacement of an element from its compound by another element which takes its place, setting the original element free.

Oxidation-reduction refers to a reaction in which there is a change in valence but no decomposition, direct union, or displacement. All of these types of reactions involve a change in valence and are therefore oxidation-reduction reactions, but common usage limits the term *oxidation-reduction* to the type of reaction mentioned above.

The Elements May Be Arranged in the Order in Which They Will Displace Each Other from Compounds.

In *displacement reactions*, an element displaces another element in a compound; for example, magnesium will displace carbon from carbon dioxide:

$$\underset{\text{magnesium}}{2\,Mg} + \underset{\text{carbon dioxide}}{CO_2} \longrightarrow \underset{\text{magnesium oxide}}{2\,MgO} + \underset{\text{carbon}}{C}$$

Iron will displace copper from a solution:

$$\overbrace{\underset{\text{iron}}{2\,Fe} + \underset{\text{copper ions}}{3\,Cu^{++}} \longrightarrow \underset{\text{iron ions}}{2\,Fe^{+++}}}^{\text{loss of electrons}} + \underset{\text{copper}}{3\,Cu}$$

(gain of electrons: $3\,Cu^{++} \rightarrow 3\,Cu$)

It was observed early in the history of modern chemistry that the elements could be listed in the order in which they would displace each other from their compounds. Such a series of elements is listed below.

Displacement Series	Electrode Potential in Volts
K	2.92
Na	2.71
Mg	2.40
Al	1.69
Zn	0.76
Fe	0.44
Pb	0.12
H	0.00
Cu	− 0.34
Ag	− 0.80

The Displacement Series Represents the Order of the Tendency of Elements to Lose Electrons.

For a long time, though the reason that elements displace each other was not known, it was assumed that such displacements involved the displacement of one element from a compound by another element which had a greater affinity for the remaining element in the compound.

Later it was found that any metal above another in the displacement series would displace a lower one from solution, the displacing metal going into solution. In the reaction given above in which iron displaced copper from solution, it is clear that such a *displacement reaction involves the loss of electrons by the higher metal in the series to form ions and the*

gain of electrons by the ions of the lower metal in solution to form the metallic element. This statement will be better understood if you will recall that *ions are formed* by the *loss of electrons by metals* and by the corresponding *gain* of *electrons by nonmetals.* A positive ion therefore represents an atom or group of atoms (radical) which has lost one or more electrons.

A metal will displace from its solution any metal lower in the displacement series. Inasmuch as this process involves a transfer of electrons, it follows that the elements at the top of the displacement series are those which lose electrons most readily. This conclusion is borne out by other facts; for example, the relative tendencies of metals to emit electrons when heated or when exposed to radiant energy are in the same order as the metals appear in the displacement series.

Any two elements in the displacement series would have a difference of potential set up between them, provided chemical action were made possible as a result of the difference in their attraction for electrons. These differences in potential are listed in the displacement series table. Such a series of elements is generally called an *electromotive*, or *electrochemical*, series. See Unit VII, Section 3, p. 496.

Chemical Cells and Batteries Are Applications of the Differences in the Tendency of Atoms to Lose or Gain Electrons.

The principle of the *chemical cell* is very simple. All that is needed is *one electrode to give up electrons and another electrode to accept electrons* and a suitable conducting medium between them. An electric current may be produced by placing any *two different metals* in a *solution* of *an electrolyte* and connecting them with a metallic conductor. The difference of potential produced by such a cell depends upon how far apart the metals are in the electromotive series. It also is possible to obtain electric currents from cells consisting of *two electrodes* of the *same metal* in *two different electrolytes* because in this case the difference of potential between the metal and the ion in solution will be different at each electrode. Cells may be prepared in which the *same metal* is placed in *different concentrations of the same electrolyte* because in this case the tendency to lose electrons depends upon the concentration of the ions in solution.

Many chemical cells are of little value because they become *polarized* easily. In the majority of cells hydrogen gas is liberated at one electrode when hydronium ions, always present in water, accept electrons, forming hydrogen gas, while the metal of the other electrode goes into solution to form metallic ions, thus giving up electrons. This hydrogen gas which is liberated forms a layer of gas around the cathode, and the

current of electricity ceases because this layer of gas is a nonconductor and also because the electrode now becomes a hydrogen electrode instead of the metallic electrode that it was before and therefore has a different potential. The *formation* of such a *layer of gas around an electrode* is called *polarization.*

Consider, for example, a simple cell consisting of a zinc rod and a carbon rod dipping into a solution of ammonium chloride. Zinc is above carbon in the electromotive series and goes into solution to form zinc ions, thus giving up electrons. In the solution there are ammonium ions, $(NH_4)^+$, and hydronium ions, $(H_3O)^+$. Inasmuch as the hydronium ions accept electrons more readily than ammonium ions, the hydronium ions accept electrons when the electrodes are connected by a metallic conductor and form water, H_2O, and hydrogen gas, H_2. This cell quickly polarizes as a result.

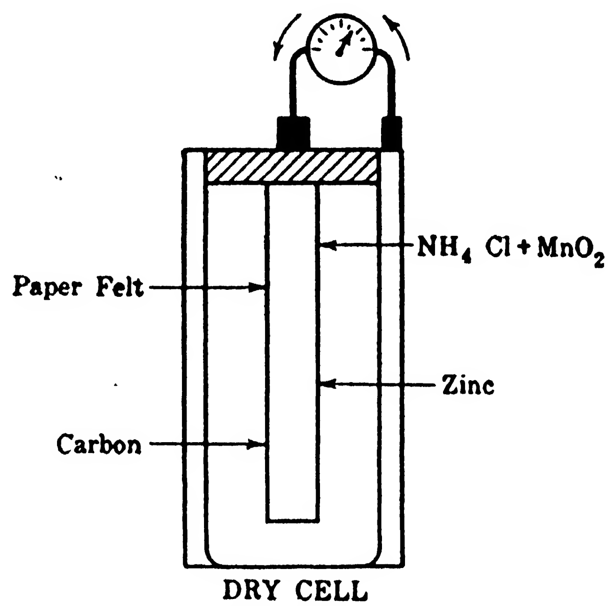


Fig. 282. Diagram of a dry cell.

The ordinary, general-purpose dry cell consists of a can of sheet zinc acting as one electrode and a carbon rod acting as the other electrode. The two electrodes are in contact with a solution of ammonium chloride and zinc chloride. This cell is, therefore, substantially the same as the one mentioned above, but the carbon rod in this case is surrounded by a moist mixture of granulated carbon, solid ammonium chloride, and manganese dioxide. The manganese dioxide acts as a depolarizer, preventing the formation of hydrogen.

In 1940 there was announced the development of a portable flashlight, smaller than a man's head, which is so powerful that it is possible to read a newspaper by its light half a mile away. It produces a beam of light of 180,000 candle power.

The *dry cell,* like most chemical cells which require a depolarizer, is *irreversible; i.e.,* it cannot be charged by running a current into it, and it must be thrown away when it is exhausted. The *lead storage battery* is an example of a *reversible cell.* It consists of an electrode of lead and another of lead peroxide, PbO_2, in contact with sulfuric acid. During discharge both electrodes become coated with lead sulfate, and the sulfuric acid in the solution is used up in the process, thus decreasing the chemical dissimilarity and the potential difference. Inasmuch as the solution of sulfuric acid decreases in specific gravity

as the sulfuric acid is removed from the solution as a battery is discharged, a hydrometer is all that is necessary to determine whether or not a battery needs charging. When the battery is charged, the electrolysis carries hydrogen to the cathode, re-forming sulfuric acid, while the oxygen at the anode restores the lead oxide, and the original condition of the battery is restored.

The difference of potential between the two electrodes of a charged storage battery is 2 volts. The voltage of a battery may be increased 2 volts for each cell added, the cells being connected in series. Thus a 6-volt battery has 3 cells, and a 12-volt battery has 6 cells. It is customary to place each pair of electrodes in separate glass or hard-rubber cells. Each electrode may consist of one, two, three, four, or more plates. The number of plates increases the surface exposed and thus increases the amount of energy that the battery can store, but it does not change the voltage. The cathode and anode plates must be kept from touching each other in order to prevent internal short circuits, so they are separated by insulators made of wood, corded hard rubber, or glass cloth which will be pervious to the sulfuric acid but will not be acted upon by it.

The storage battery is used most extensively in automobiles; without a storage battery a self-starter would be impossible. The battery is kept in the charged condition in the automobile by a generator which is operated when the engine is running. Storage batteries for modern cars must be very rugged because they not only furnish the energy to start the car, but they also operate the lights, radios, ignition systems, sirens, and cigarette-lighters; in addition, they must withstand severe and almost constant jolting about and must have a large reserve of power for starting cars in the winter.

Storage batteries are used to operate radio sets in remote communities not served by electrical lines. They are also used in private lighting plants to supply power when the generator is not in use. Submarines are operated by the energy from storage batteries when they are submerged.

Edison invented another very rugged but less efficient type of storage battery consisting of a negative electrode of iron oxide in perforated steel pockets and a positive electrode of nickel hydrate in perforated steel tubes immersed in a solution of potassium hydroxide. This battery is especially valuable because it may be discharged to zero voltage, accidentally charged in reverse, or short-circuited without permanent injury. It is relatively light in weight, compact and durable, and has a long life. Severe vibrations and concussions do not affect it. Such storage batteries are used for lighting and air conditioning of

railroad cars, for electric industrial trucks and tractors, for lighthouses, for propelling small boats, for store delivery trucks, for mine locomotives, for electric cap lamps for miners' lights, and many other uses that are characteristic of modern industrial civilization.

In 1899 *E. W. Junger* invented the cadmium-nickel battery in Sweden. This battery has been used industrially in Europe for about ten years. It is quite similar to the nickel-iron battery in construction and discharge characteristics.

Displacement Reactions Are Special Examples of Oxidation and Reduction.

When *oxygen combines with any substance*, the process is called *oxidation*, and *when oxygen is removed from a compound*, the process is called *reduction*. Thus the rusting of iron is oxidation because this process, as already mentioned, involves the combining of iron with oxygen to form iron oxide; oxygen is an example of an *oxidizing agent*. On the other hand, when iron ore is treated with coke in a blast furnace, the process is reduction because in this case the iron oxide is reduced to iron; carbon is an example of a *reducing agent*. The simplest example of oxidation and reduction is the burning of hydrogen in air to form water:

$$\underset{\text{hydrogen}}{2\,H_2} + \underset{\text{oxygen}}{O_2} \longrightarrow \underset{\text{water}}{2\,H_2O}$$

In this case the *hydrogen* is said to be *oxidized* because *oxygen is added* to it to form water. On the other hand, *oxygen* is said to be *reduced* because *hydrogen is added* to it to form water.

Organic compounds may be oxidized in steps; for example, the following compounds represent progressive stages in the oxidation of methane:

$$\underset{\text{methane}}{CH_4} \longrightarrow \underset{\text{methyl alcohol}}{CH_3OH} \longrightarrow \underset{\text{formaldehyde}}{HCHO} \longrightarrow \underset{\text{formic acid}}{HCOOH} \longrightarrow \underset{\text{carbon dioxide}}{CO_2}$$

$$CH_4 \xrightarrow[\text{oxygen added}]{} CH_4O \xrightarrow[\text{hydrogen removed}]{} CH_2O \xrightarrow[\text{oxygen added}]{} CH_2O_2 \xrightarrow[\text{hydrogen removed}]{} CO_2$$

In this reaction and many other reactions it is apparent that *oxidation* may be the result of either *an addition of oxygen* or *a removal of hydrogen*. *Reduction* would then be the *removal of oxygen* or the *addition of hydrogen*. Thus the terms *oxidation* and *reduction* are extended to include reactions in which *hydrogen is added or removed*.

Oxidation and *reduction* may also be interpreted in terms of *valence changes*. Inasmuch as *uncombined elements* represent no *combining*

power, their valence is said to be *zero.* The above reaction may now be rewritten to show valence changes:

$$\begin{array}{lcccc} \text{Valence} & 0 & & 0 & & 2(+2-2) \\ & 2\,H_2 & + & O_2 & \longrightarrow & 2\,H_2O \end{array}$$

In this case hydrogen, H_2, has changed in valence from zero to $2 \times (+1)$. It has therefore increased in valence.

Inasmuch as hydrogen is oxidized in the above reaction, *an increase in valence must* therefore *be oxidation.* By the same reasoning the *loss in valence* of oxygen *must be reduction.*

We now have a new and more general definition of oxidation and reduction. *Oxidation is the increase in the positive valence, while reduction is a decrease in positive valence.* Thus *many reactions which involve neither oxygen nor hydrogen are still oxidation-reduction reactions* because the *valences of elements are changed* in these reactions; in fact *every reaction in which there is a change of valence is an* ***oxidation-reduction*** *reaction.* The term *oxidation-reduction reaction* is used because in every reaction which involves oxidation there is always a loss in positive valence by one atom which exactly equals the gain in positive valence of another. An example of an oxidation-reduction reaction which involves no oxygen or hydrogen is given as follows: when a globule of mercury is rolled over a sheet of paper covered with mercuric chloride, $HgCl_2$, it leaves a fluorescent path when exposed to ultraviolet light because the mercury forms mercurous chloride, HgCl, which, unlike mercuric chloride, $HgCl_2$, is fluorescent.

$$\begin{array}{lcccc} \text{Valence} & +2-2 & & 0 & & 2(+1-1) \\ & HgCl_2 & + & Hg & \longrightarrow & 2\,HgCl \\ & \text{mercuric chloride} & & \text{mercury} & & \text{mercurous chloride} \end{array}$$

In this case the *mercuric* mercury is changed to *mercurous* mercury; *when metals have two valences, the lower valence* is indicated by the suffix *ous* as in mercur*ous* or cupr*ous*, and the *higher valence* is indicated by the suffix *ic* as in mercur*ic* and cupr*ic*. This reaction represents a decrease in positive valence and is therefore reduction. The free mercury increases in positive valence and is therefore oxidized.

According to the electron theory, changes in valence are the result of a loss or gain of electrons; thus *oxidation* and *reduction fundamentally involve* a *gain* or *loss* of *electrons* by atoms or ions. Inasmuch as an increase in positive valence is oxidation and inasmuch as this change is accomplished by the loss of electrons, *oxidation is the loss of electrons* or *de-electronization,* as the process is sometimes called. *Reduction* must therefore be a *gain of electrons,* or *electronization.*

Oxidizing and Reducing Agents Are Substances Which Gain and Lose Electrons.

The separation of metals from their compounds in metallurgy is essentially a process of reduction, because electrons must be added to the metal in the compound to set it free. Coal is used to reduce iron ore:

gain of electrons

$$\underset{\text{iron oxide}}{\overset{2(+3\,-3)}{2\,Fe_2O_3}} + \underset{\text{carbon (coal)}}{\overset{0}{3\,C}} \longrightarrow \underset{\text{iron}}{\overset{0}{4\,Fe}} + \underset{\text{carbon dioxide}}{\overset{3(+4\,-4)}{3\,CO_2}}$$

loss of electrons

An electric current is a stream of electrons and therefore serves as a reducing agent. Sodium, aluminum, magnesium, and other metals which have a relatively poor attraction for electrons are best separated from their compounds by electrolysis. These metals separate at the cathode because electrons are given off at this pole.

Nonmetals have a relatively high attraction for electrons, but these elements may be separated from their compounds at the anode by electrolysis because electrons are removed from substances at the anode. Chlorine, bromine, iodine, and oxygen may be prepared by electrolysis. Oxygen has an attraction for electrons which is greater than that of chlorine, and oxygen may therefore be used to liberate chlorine from its compounds. Chlorine, in turn, has an attraction for electrons which is greater than that of iodine, and chlorine will therefore liberate iodine from its compounds.

gain of electrons

$$\underset{\text{chlorine}}{\overset{0}{Cl}} + \underset{\text{sodium iodide}}{\overset{+1\,-1}{NaI}} \longrightarrow \underset{\text{iodine}}{\overset{0}{I}} + \underset{\text{sodium chloride}}{\overset{+1\,-1}{NaCl}}$$

loss of electrons

In electrolysis, reduction takes place at the cathode and oxidation takes place at the anode.

In the reaction

loss of electrons

$$\overset{0}{2(H_2)} + \overset{0}{O_2} \longrightarrow \overset{2(+2\,-2)}{2(H_2O)}$$

gain of electrons .

hydrogen loses electrons, and oxygen gains electrons. Similarly, in the reaction of sodium with water, sodium goes into solution to form sodium ions, Na^+, losing electrons in the process, while hydronium ions, $(H_3O)^+$, accept electrons and form water and hydrogen gas.

loss of electrons

$$\overset{0}{2\,Na} + 2(OH)^-,\ 2(H_3O)^+ \longrightarrow 2\,Na^+,\ 2(OH)^- + \overset{0}{H_2} + 2\,H_2O$$

gain of electrons

This reaction is typical of all displacement reactions in that it involves a transfer of electrons.

Electrolysis, Which Is Cell Action in Reverse, Is Also an Oxidation-reduction Reaction.

When metals are plated by electrolysis, the metal goes into solution at one electrode and plates out at the other; thus, in silver-plating, a brass spoon may be used as one electrode and a bar of silver as the other electrode, the electrolyte being a solution of some silver salt.

Electrons are sent to the brass spoon and are taken up by the silver ions surrounding the brass spoon to form metallic silver, which is then deposited as a plate on the spoon.

$$\underset{\text{silver ions}}{Ag^+} + \overset{\text{gain of electrons}}{\text{electrons}} \longrightarrow \underset{\text{metallic silver}}{Ag^0}$$

This reaction is clearly electronization (reduction). At the other electrode electrons are removed from the silver to form silver ions.

$$\underbrace{Ag^0 \longrightarrow}_{\text{loss of electrons}} Ag^+ + \text{electrons}$$

This reaction is de-electronization (oxidation).

Electrolysis Is a Very Important Metallurgical Process.

The following metals are now produced or refined by electrolysis: sodium, aluminum, magnesium, zinc, lead, copper, nickel, cadmium, bismuth, cobalt, and beryllium.

Fifty years ago the price of metallic sodium was $2.00 per pound; today it is $0.14 per pound. The world production of sodium exceeds 300,000 tons per year. Sodium was formerly used to separate aluminum from its compounds, but it is now used as a reducing agent chiefly in the organic chemical industry.

In 1886, 16 metric tons of aluminum were produced at a cost of about $8.00 per pound; in 1941 the Aluminum Company of America in the United States alone produced 200,000 tons of aluminum at about $0.17 per pound; this company's production in 1941, as its $200,000,000 expansion program neared completion, exceeded 300,000 tons; in 1942, 350,000 tons. In 1941 the Reynolds Metal Company was producing 50,000 tons; and the United States Government planned to build plants to produce an additional 600,000 tons of aluminum per year to meet the needs of an expanding airplane industry. The entrance of the United States into World War II considerably expanded the above production program.

Magnesium is a competitor of aluminum. Magnesium is a lighter metal than aluminum, and its alloys are very strong.

A new process has been developed for the production of magnesium from magnesite (magnesium carbonate), a very abundant rock, by reduction with coke in an electric furnace. This promises to make magnesium available at half the price of aluminum. Dow metal contains 90 per cent or more of magnesium, plus 10 per cent or less of aluminum, plus small amounts of other metals. Its use in airplane construction is well known.

Only a few hundred pounds of cadmium were produced in 1890, but the world production in 1940 was 12,000,000 pounds. Cadmium is replacing zinc for many purposes because it produces a protective coating on iron which is superior to it under some circumstances.

Electrolysis is being used increasingly in the organic chemical industry to oxidize and reduce organic compounds. The advantage of electrolytic oxidation and reduction is that it can be carried out at ordinary temperatures and pressures and can be accurately controlled.

The melting-point of beryllium is 1285° C., 185° above the melting-point of copper. A very little beryllium added to gold makes the gold very hard. Two per cent of beryllium added to copper gives it the strength of steel, in fact, a beryllium-copper chisel may be hammered through soft steel. Two per cent of beryllium added to nickel gives it a tensile strength after heat treatment of 260,000 pounds per square inch, as compared with only 60,000 pounds per square inch for structural steel. From 0.01 to 0.02 per cent of beryllium imparts a smooth grain to copper castings and improves the electrical conductivity of copper as much as 20 per cent and at the same time makes the copper more resistant to corrosion. From 1 to 5 per cent of beryllium in silver prevents it from tarnishing with sulfur and sulfur compounds.

Only those metals which are below hydrogen in the displacement series can be prepared by electrolysis of their water solutions. All metals above hydrogen in the displacement series, such as sodium, magnesium, aluminum, and beryllium, are prepared by the electrolysis of their melted compounds.

A very interesting recent development is an electrolytic method of producing a high polish of mirror-like quality on steel, nickel, copper, brass, and zinc that protects them against corrosion.

STUDY QUESTIONS

1. Which type of elements loses electrons most readily?
2. What are the two main types of chemical reactions?
3. Give examples of each of the four main types of electron transfer.

4. What is the displacement series?
5. Why is the displacement series sometimes called the electrochemical, or electromotive, series?
6. Explain in terms of the theory of atomic structure why carbon is such a good reducing agent.
7. Explain in terms of the theory of atomic structure why sodium is a more powerful reducing agent than carbon.
8. Explain the polarization of a cell.
9. Explain the action of the ordinary dry cell.
10. Explain what takes place when a lead storage battery is charged and discharged.
11. Define oxidation in terms of oxygen, hydrogen, valence, and electrons.
12. What is the true nature of all oxidation-reduction reactions?

UNIT VIII

SECTION 7

ACIDS ARE PROTON-DONORS AND BASES ARE PROTON-ACCEPTORS

In all the reactions studied up to this point the reactions were either of the double decomposition type, which simply involved the removing of ions from a solution, or of the electron transfer type. This Section will describe two types of compounds, acids and bases, which will enter into double decomposition reactions and electron transfer reactions, but which are fundamentally different from all other compounds in that they lose and gain protons.

Acids Owe Their Properties to Hydronium Ions.

Before the discovery of the electrical nature of matter, the class of substances known as *acids* was recognized by the properties common to all acids. Thus an *acid* is *a substance whose water solution* (1) *has a sour taste,* (2) *changes certain substances called indicators to develop a color different from that shown with bases,* (3) *neutralizes bases* (*i.e., reacts with bases in such a way that the properties of both the acid and base disappear*), (4) *reacts with metals above hydrogen in the displacement series to produce hydrogen gas.*

It has been noted that hydrogen is the one substance that is common to all acids, so it is only natural to attribute the acid properties to hydrogen.

Acids are familiar in everyday life. Citrus fruits taste sour because of the presence of citric acid in these fruits; tartaric acid imparts tartness to grapes; acetic acid is the acid in vinegar; muriatic acid (hydrochloric acid) is used to clean metal surfaces for soldering and to dissolve cement and mortar spots on brick and tile; hydrochloric acid is present in the gastric juice and accounts for the sour taste of regurgitated stomach contents; oxalic acid dissolves iron rust stains in clothes.

According to the *theory of ionization, an acid is a solution containing hydronium ions.*[1] The hydrogen compounds which react with water to

[1] The properties of acids were formerly ascribed to the presence of hydrogen ions (protons, H^+) in their solutions. The modern theory presented in this text differs from the above theory in that it ascribes the properties of acids to hydronium ions, which, as already pointed out, are considered to be formed by the combining of hydrogen ions with water molecules.

form hydronium ions are also termed acids, although they might better be termed *acid-formers*.

There are three general types of *acid-formers:*

1. *Hydrides of nonmetals or nonmetallic radicals.* Examples, HCl, $H(C_2H_3O_2)$.

A hydride is a compound of an element or a radical with hydrogen,

$$\underset{\text{hydrogen chloride}}{HCl} + \underset{\text{water}}{H_2O} \longrightarrow \underset{\text{hydronium ion}}{(H_3O)^+}, \underset{\text{chloride ion}}{Cl^-}$$

$$\underset{\text{hydrogen acetate}}{HC_2H_3O_2} + \underset{\text{water}}{H_2O} \longrightarrow \underset{\text{hydronium ion}}{(H_3O)^+}, \underset{\text{acetate ion}}{(C_2H_3O_2)^-}$$

2. *Oxides of nonmetals or nonmetallic radicals.* Examples, Cl_2O_3, $(C_2H_3O)_2O$.

$$\underset{\text{chlorine trioxide}}{Cl_2O_3} + \underset{\text{water}}{3\ H_2O} \longrightarrow \underset{\text{hydronium ion}}{2(H_3O^+)}, \underset{\text{chlorite ion}}{2(ClO_2)^-}$$

$$\underset{\substack{\text{acetyl oxide}\\ \text{(acetic anhydride)}}}{(C_2H_3O)_2O} + \underset{\text{water}}{3\ H_2O} \longrightarrow \underset{\text{hydronium ion}}{2(H_3O^+)}, \underset{\text{acetate ion}}{2(C_2H_3O_2)^-}$$

3. *Hydroxides of nonmetals or nonmetallic radicals.* Examples, $P(OH)_3$, $SO_2(OH)_2$.

$$\underset{\text{phosphorous hydroxide}}{P(OH)_3'} + \underset{\text{water}}{3\ H_2O} \longrightarrow \underset{\text{hydronium ion}}{3(H_3O)^+}, \underset{\text{phosphite ion}}{(PO_3)^{---}}$$

$$\underset{\substack{\text{sulfuryl hydroxide}\\ \text{(hydrogen sulfate, or}\\ \text{sulfuric acid)}}}{SO_2(OH)_2} + \underset{\text{water}}{2\ H_2O} \longrightarrow \underset{\text{hydronium ion}}{2(H_3O)^+}, \underset{\text{sulfate ion}}{(SO_4)^{--}}$$

In the older terminology HCl would have been called an acid, and its solution would have been said to have contained hydrogen ions, H^+. according to the equation:

$$HCl \longrightarrow H^+, Cl^-$$

This equation is based on the assumption that HCl is ionized and that when it is dissolved in water the water breaks down the interionic attraction, thus freeing H^+ and Cl^- ions. This reaction is incorrect in the first place because HCl is a covalent compound, *i.e.*, it does not ionize when free from water. In the second place H^+ ions, *i.e.*, protons, do not exist in the free state but attach themselves to anything that will accept them. Water reacts with HCl because water will combine with protons.

$$HCl + H_2O \longrightarrow (H_3O), Cl^-$$

In the same way NH_3 reacts with HCl because NH_3 will combine with protons.

$$NH_3 + HCl \longrightarrow (NH_4)^+, Cl^-$$

An Acid Is a Proton-donor.

The characteristic chemical reactions of acids are given as follows:

1. *Acids react with metals* such as sodium, that have a smaller attraction for electrons than hydronium ions have, to give hydrogen gas.

loses an electron

$$\underset{\text{hydrochloric acid}}{2(H_3O)^+, Cl} + \underset{\text{sodium}}{Na} \longrightarrow \underset{\text{sodium chloride}}{Na^+, Cl^-} + \underset{\text{hydrogen}}{H_2} + \underset{\text{water}}{H_2O}$$

gains an electron

This reaction is obviously an example of a displacement type of electron transfer.

2. *Acids react with ammonia,* NH_3.

$$\underset{\text{hydrochloric acid}}{(H_3O)^+, Cl^-} + \underset{\text{ammonia}}{NH_3} \longrightarrow \underset{\text{ammonium chloride}}{(NH_4)^+, Cl^-} + \underset{\text{water}}{H_2O}$$

In this reaction the hydronium ion, $(H_3O)^+$, gives up a proton, H^+, to ammonia, NH_3.

3. *Acids react with bases.* ***Bases*** are recognized by their characteristic properties; *a base is a substance whose water solution feels slippery, tastes bitter or alkaline, changes the color of indicators to a color different from that produced by acids, and neutralizes acids to form salts.* Some common bases are: the weak base, ammonium hydroxide, NH_4OH, a 3 per cent solution of which is the ordinary household aqua ammonia; the strong base, sodium hydroxide, NaOH, which is commonly known as soda lye; the strong base, potassium hydroxide, KOH, known as potash lye; and the mild base, calcium hydroxide, $Ca(OH)_2$, known as hydrated lime, which is used in making mortar and plaster. Strong bases, such as sodium hydroxide and potassium hydroxide, are called *alkalies,* because they are prepared from hydroxides of the alkali metals.

In the reaction of hydrochloric acid with sodium hydroxide, it is evident that the hydronium ion, $(H_3O)^+$, gave up a proton, H^+, to the hydroxyl ion, $(OH)^-$, to form water.

$$\underset{\substack{\text{hydrochloric acid}\\ \text{(acid)}}}{(H_3O)^+, Cl} + \underset{\substack{\text{sodium hydroxide}\\ \text{(base)}}}{Na^+, (OH)^-} \longrightarrow \underset{\text{water}}{2\,H_2O} + \underset{\substack{\text{sodium chloride}\\ \text{(salt)}}}{Na^+, Cl^-}$$

In the reactions of hydrochloric acid with ammonia and with sodium hydroxide, the fundamental reaction was that in which hydronium ions gave up protons to another substance.

Inasmuch as this property of giving up protons to other substances is characteristic of acids only, acids are called *proton-donors.*

Bases Are Proton-acceptors.

In the above reactions NH_3 and $(OH)^-$ accepted protons. *Any substance which accepts protons is called a base.* Common usage restricts the use of the term *base* to one kind of proton-acceptor only, namely, the hydroxyl ion. The base is really a hydroxyl ion, but in usage the *base* is considered to be the *substance which produces hydroxyl ions in solution.* A *weak base* is a substance which exhibits a *weak tendency to accept protons;* in other words, it is a substance which is largely covalent in nature and does not produce a high concentration of hydroxyl ions.

Bases will react with certain metals.

gain of electrons

$$\underset{\text{sodium hydroxide}}{2\,Na^+,\,(OH)^-} + \underset{\text{zinc}}{Zn} \longrightarrow \underset{\text{sodium ions}}{2\,Na^+} + \underset{\text{zincate ions}}{(ZnO_2)^{--}} + \underset{\text{hydrogen}}{H_2}$$

loss of electrons

This reaction is obviously an example of a displacement type of electron transfer reaction, in which Zn displaces H from $(OH)^-$. Strong bases, such as sodium hydroxide, NaOH, or potassium hydroxide, KOH, react with such metals as zinc, aluminum, and silicon with an evolution of hydrogen, but the typical reactions of bases are those in which they neutralize acids, *i.e., accept protons.* Neutralization reactions will be studied in the next Section.

STUDY QUESTIONS

1. Define an acid (*a*) in terms of its properties, (*b*) in terms of its ions, (*c*) in terms of proton transfer.
2. Define a base (*a*) in terms of its properties, (*b*) in terms of its ions, (*c*) in terms of proton transfer.
3. What are the characteristics peculiar to acids and bases?
4. How are acids prepared?
5. How are bases prepared?
6. Give two chemical properties of acids.
7. Give two chemical properties of bases.
8. Mention some common acids and their uses.
9. Mention some common bases and their uses.

UNIT VIII

SECTION 8

THE TRANSFER OF PROTONS CONSTITUTES AN IMPORTANT TYPE OF ELECTROVALENT REACTION

Introduction.

All electrovalent reactions may be classified into three main types: (1) those involving recombination of ions, (2) those involving electron transfer, and (3) those involving proton transfer. Previous sections have dealt with the first two types of reactions. Section 7 dealt with acids and bases and their reactions. This Section will take up the third type of reaction, that of proton transfer, which is characteristic of acids and bases only.

Neutralization Is the Action of Hydronium Ions with Hydroxyl Ions to Form Water.

When acids react with bases, water and salts are produced. This process is called *neutralization*. Thus, hydrochloric acid reacts with sodium hydroxide to produce sodium chloride and water.

$$\underset{\text{hydrochloric acid}}{(H_3O)^+, Cl^-} + \underset{\text{sodium hydroxide}}{Na^+, (OH)^-} \longrightarrow \underset{\text{sodium chloride}}{Na^+, Cl^-} + \underset{\text{water}}{2\,H_2O}$$

The sodium ions, Na^+, and chloride ions, Cl^-, do not change. The only change observed is that hydronium ions, $(H_3O)^+$, combine with hydroxyl ions, $(OH)^-$, to produce water. A study of all other neutralization reactions will show that the above reaction is the only change that takes place. *Neutralization* is therefore essentially a *combination of hydronium ions*, $(H_3O)^+$, *with hydroxyl ions*, $(OH)^-$, *to form water.*

$$(H_3O)^+ + (OH)^- \longrightarrow 2\,H_2O$$

The Completion of Neutralization Reactions May Be Indicated by Certain Colored Weak Proton-donors.

Neutralization reactions, as already pointed out, are reactions in which protons are transferred from acids to bases to form salts and water. Such reactions are very important, because in this way many salts are prepared. In many cases it is desired to neutralize acids and

bases. Thus a strong acid, if spilled on a textile or the skin, will cause damage unless the acid is neutralized. The acid may be neutralized with a strong base; but if an excess of strong base is added, just as much harm will be done by the base as would be done by the acid. The acid may be neutralized safely, however, by the use of the weak base, ammonium hydroxide, NH_4OH, because the excess of this base does no harm, inasmuch as it decomposes to form water and ammonia gas, the latter escaping into the air.

In the manufacture of soap, a strong base, such as sodium hydroxide, reacts with a weak acid, such as palmitic acid, to form a salt. Inasmuch as an excess of either acid or base is harmful to the skin, any soap that comes into contact with the skin should be neutral. How can one tell when an acid or base has been completely neutralized, leaving no trace of excess of acid or base?

Of course, if one can measure the amount of acid present, he can calculate the amount of base needed and then add exactly that amount. The amount of acid present can be determined by titration with a standard solution of base. Titration with a standard solution means adding a solution of a base of known concentration to an acid in such a way that the exact amount of base solution required to neutralize the acid can be measured.

But the problem of knowing when the end point has been reached still remains. This problem is solved by means of certain dyes which are proton-donors. Such dyes are called *indicators*, because they indicate the approach to the *end point*, *i.e.*, the point at which the concentration of hydronium ions is the same as that, or near that, in pure water. When the dye gives up protons, its color is different from that which it possesses before donating its protons. If there are already many hydronium ions present in the solution, the dye will not give up its protons; but, as the hydronium-ion concentration decreases, the dye gives up more and more protons until its color becomes changed. Thus the color of methyl orange is pink in an acid solution but yellow in a basic solution. The end point is taken as that point just before the production of the basic color. Many of the dyes in nature are weak proton-donors. Thus the color of tea is changed when acid (lemon juice) is added. Grape juice is purple in color but changes to a green color when the acid is neutralized. The compounds which are responsible for the colors in wines, vinegar, purple cabbage, and many flowers are indicators. The colors in your clothes may be changed by adding acids, and if the acid is neutralized quickly enough, the original colors may often be restored.

The proton activity (concentration of hydronium ions) may also

be determined by electrometric means. A cell may be constructed in which one electrode dips into a solution that maintains a constant potential on this electrode. The other electrode dips into the solution of unknown hydronium-ion concentration. The potential of this electrode changes with the change in the concentration of the hydronium ions in the solution, so that the electromotive force of the cell itself will change. By measuring the electromotive force of this cell as titration proceeds, the end point will be evident, for at this point the change in the electromotive force of the cell will be greatest for a given addition of acid or base.

It is important to note here that pure water is slightly electrovalent and that there is therefore always a small concentration of hydronium ions and hydroxyl ions in equilibrium with the water. The product of the concentrations of these ions is always constant. At the neutral point the concentrations of the hydronium and hydroxyl ions are equal. An acid solution has an excess of hydronium ions, and a basic solution has an excess of hydroxyl ions.

The concentration of the hydronium ions is expressed in pH (*i.e.*, the logarithm of the reciprocal of the hydronium-ion concentration). pH 7 is neutral, any value above pH 7 is alkaline, and any value below pH 7 is acid.

The measurement of hydronium-ion concentration and the maintenance of its concentration within fixed limits are of importance in many industries. For example, water purification by coagulation and filtration, certain types of sewage-disposal methods, the corrosion of boilers, the bleaching, laundering, and dyeing of textiles, the manufacture of gelatine, and the preparation of certain drugs are only a few cases in which success depends on careful regulation of the hydronium-ion concentration. Certain plants grow best in basic soils, others grow best in acid soils, and bacterial cultures must have just the right hydronium-ion concentration for growth.

Hydrolysis Is the Reverse of Neutralization.

Whenever a substance reacts with water otherwise than by simple addition, the process is called *hydrolysis*. One type of hydrolysis, restricted to covalent compounds, is the action of water with such substances as proteins or starches to form simpler substances, such as amino acids or sugars.

In electrovalent chemistry, *hydrolysis is the action of water with salts of weak acids and bases to form acids and bases. The process is the reverse of neutralization*, and the only reason that it can take place is that either the hydroxyl ions or the hydronium ions of water combine with

metallic or nonmetallic ions to form a slightly electrovalent covalent acid or base or both.

One may summarize the actions in neutralization and hydrolysis as follows: *Neutralization is a reaction in which protons are donated by hydronium ions to hydroxyl ions to form the weakly electrovalent covalent compound, water. Hydrolysis, on the other hand, is the process in which the hydronium ions or the hydroxyl ions formed by the dissociation of water donate their charges to other negative or positive ions to form weakly electrovalent covalent compounds.*

There Are Many Important, Interesting Applications of Hydrolysis.

Baking powders are mixtures of sodium bicarbonate with some salt which will hydrolyze to produce an acid solution and with starch to keep the mixture dry so that the desired reaction will not take place before it is required.

When acid is added to sodium bicarbonate, carbon dioxide is produced. Thus:

$$\underset{\text{hydrochloric acid}}{(H_3O^+),\ Cl^-} + \underset{\text{sodium bicarbonate}}{Na^+,\ (HCO_3)^-} \longrightarrow \underset{\text{sodium chloride}}{Na^+,\ Cl^-} + \underset{\text{water}}{H_2O} + \underset{\text{carbon dioxide}}{CO_2}.$$

The essential reaction here is:

$$(H_3O)^+ + (HCO_3)^- \longrightarrow 2\,H_2O + CO_2.$$

The carbon dioxide produced in this reaction raises the bread. Baking soda is often added to sour milk in making bread. In this case, the lactic acid in the sour milk replaces the acid-forming salt in the baking powder. The salts generally used in baking powders are:

$NaAl(SO_4)_2$	sodium aluminum sulfate (sometimes erroneously called alum but more often referred to as S.A.S.)
$CaHPO_4$	calcium acid phosphate
$KHC_4H_4O_6$	potassium acid tartrate (cream of tartar)

Perspiration deodorants generally consist of solutions of aluminum chloride or sulfate, or iron chloride or sulfate. These salts hydrolyze to form acids which deodorize the odor-producing substances accompanying perspiration under the arm, and also act as non-perspirants.

The "foamite" type of fire-extinguisher uses alum, $KAl(SO_4)_2 \cdot 12\,H_2O$, which hydrolyzes to form an acid solution which will liberate carbon dioxide upon contact with sodium bicarbonate.

Soap and such detergents as borax, trisodium phosphate, and sodium carbonate owe their detergent action in part, at least, to the basic properties of their water solutions. These substances are salts of strong bases and weak acids and therefore hydrolyze to form basic solutions.

A *detergent* is a material which cleans by chemical action rather than by solvent action or mechanical means.

Oranges produce a basic reaction in the human body, although they are definitely acid in nature, because the excess citric acid, being an organic compound, is burned up in the body to form carbon dioxide and water and is thus eliminated, while the sodium salts in the orange juice, being salts of a strong base with a weak acid, hydrolyze to form basic solutions.

Certain substances, called *buffers*, are very important in maintaining a nearly constant hydronium-ion concentration in the human body. An excess or deficiency of hydronium ions results in disorders which are generally described as *acidosis*, *alkalosis*, or *hyper-* and *hypo-acidity*. Buffer substances must be able to neutralize both acids and bases. Disodium phosphate is a good buffer substance; inasmuch as it is an acid salt, it will neutralize bases, and inasmuch as it will accept protons, it will neutralize acids.

Proteins are capable of reacting with either acids or bases and thus act as buffers, but inasmuch as they are altered somewhat in these reactions and also because they are the substances from which living tissue is made, it is obvious that this reserve should not be overworked.

Baking soda is an excellent buffer substance; it will react with acids and is therefore often taken internally to relieve acid indigestion. Baking soda acts as an acid because it is an acid salt; and it acts as a base because it accepts protons to form a weakly electrovalent covalent compound.

STUDY QUESTIONS

1. Define *neutralization* and illustrate with some examples.
2. Define *hydrolysis* and illustrate with some examples.
3. What types of salts hydrolyze, and why?
4. Explain the action of baking powders.
5. How may one tell when an acid solution is just neutralized by addition of a solution of a base?
6. Why do all soaps produce a basic reaction when they are dissolved in water?
7. What is a buffer substance? Give an example.
8. Why does acid orange juice act as a base in the body?
9. Explain the action of the foamite type of fire-extinguisher.
10. Why are buffer substances of importance in the human body? What types of substances act as buffers in the human body?
11. What are the ingredients in the "S.A.S." type of baking powder?
12. Explain the action of indicators.
13. Why is baking soda a good perspiration deodorant?

UNIT VIII

SECTION 9

COVALENT REACTIONS, WHICH INVOLVE THE SHARING OF PAIRS OF ELECTRONS, ARE CHARACTERISTIC OF ORGANIC COMPOUNDS

Introduction.

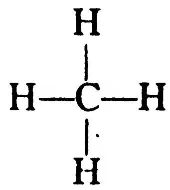
Up to this point our attention has been given largely to electrovalent compounds and electrovalent reactions, in which there have been transfers of electrons or protons. We now turn to that branch of chemistry in which electrons are *shared* rather than *transferred*. As already indicated, such reactions produce what are known as *covalent* compounds. Many inorganic compounds are electrovalent, while the majority of organic compounds are covalent. This Section will introduce some of the fundamental principles of organic chemistry.

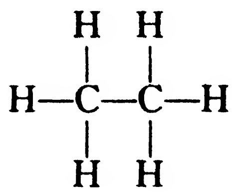
Organic Chemistry Is the Chemistry of Hydrocarbons and Compounds of Hydrocarbon Radicals.

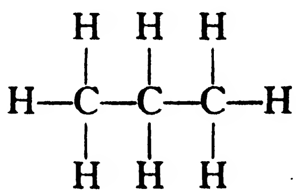
The element, carbon, is remarkable for the large number of compounds that it forms. The number of different carbon compounds is at least 250,000, or about twice as many as have been discovered for all of the other elements put together. This large number of compounds has been accounted for by assuming that carbon atoms are able to share electrons with each other to form long chains or ringlike structures.

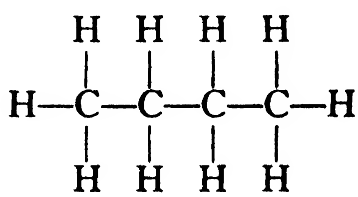
There are several series of hydrocarbons (*i.e.*, compounds of carbon with hydrogen) in which carbon atoms form chains. One series of hydrocarbons, called the paraffins, is found in natural gas and petroleum. This series is composed of saturated hydrocarbons (*i.e.*, hydrocarbons which form derivatives only by substitution, because there are no unsatisfied valences). The first eight members in this series are: [1]

[1] Every valence bond indicated in structural formulas of organic compounds represents a pair of shared electrons.

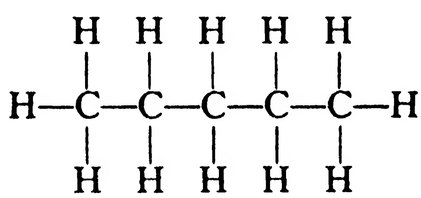
Methane 

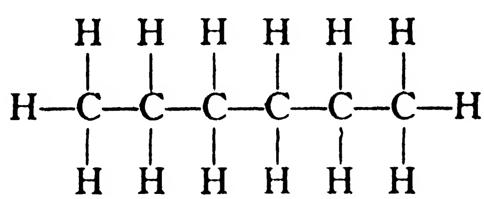
Ethane 

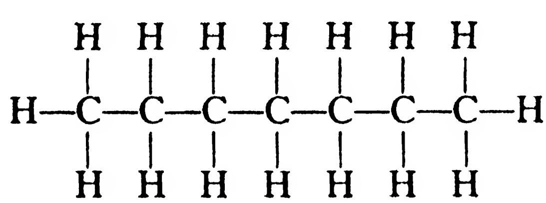
Propane 

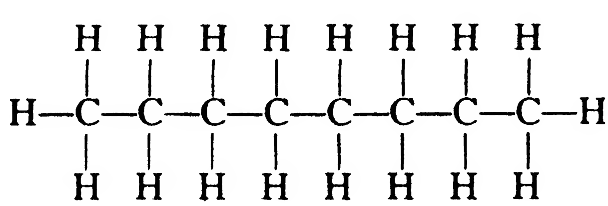
Butane 

Gases — found in natural gas

Pentane 

Hexane 

Heptane 

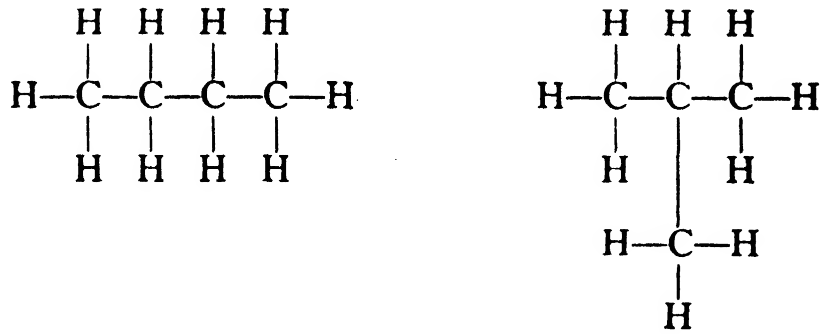
Octane 

Liquids — found in petroleum

Hydrocarbons with as many as 128 carbon atoms in a chain have been identified. These hydrocarbons are called the *paraffins* because paraffin-wax consists primarily of the higher members of the saturated series of hydrocarbons.

There Are Many Isomers among Covalent Compounds.

Two butanes of different structural formulas are known:



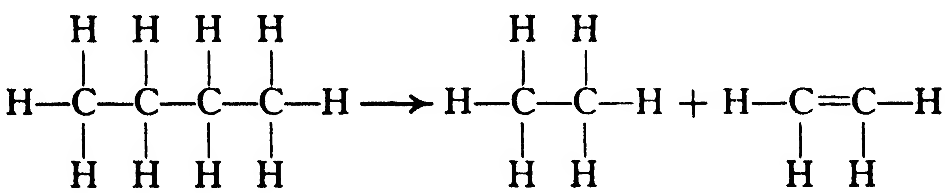
These compounds have the *same empirical formula*, C_4H_{10}, *but their structural formulas* and *their properties are somewhat different.* Such compounds are called *isomers.* Three pentanes, six hexanes, and nine heptanes are known. As the number of carbon atoms increases, the possibilities of isomerism likewise increase very rapidly. Thus there are 75 theoretically possible decanes, and a hydrocarbon with thirteen carbon atoms could exist in 802 isomeric forms. Isomerism thus helps to account for the large number of organic compounds.

Isomerism is even more pronounced among the compounds of hydrocarbon radicals, as we shall see later.

Chain Hydrocarbons May Be Cracked.

Large molecules of chain hydrocarbons may be heated under pressure and cracked to form smaller molecules. This discovery has been of tremendous importance in the petroleum industry, because it makes possible the production of gasoline in large quantities, when desired, by cracking kerosene, fuel oils, and the other fractions of petroleum for which there is relatively little demand.

When saturated hydrocarbons are cracked, unsaturated compounds are produced. Thus, if butane were cracked, it might produce an unsaturated hydrocarbon, as follows:



Every carbon atom must share four electrons. In case there is nothing with which to share one or more of its electrons, it shares two or more electrons with other carbon atoms, but the most stable arrangement is made by sharing only one electron with another carbon atom. A double union would seem to indicate strength, but it actually creates weakness for reasons which are now understood but which we need not

enter into. Such a compound is called *unsaturated*, because it can form compounds by addition as well as by substitution, as will be mentioned later.

These unsaturated compounds contained in cracked gasoline are an actual advantage, because they raise its antiknock value.

A large nitrogen-fixation plant in California obtains carbon and hydrogen by cracking the hydrocarbons in natural gas. The hydrogen thus obtained is combined with the nitrogen of the air, which is separated by liquefying and boiling the air, to produce ammonia.

A type of process which resembles cracking is *covalent hydrolysis. Hydrolysis* requires water and is usually activated by hydronium or hydroxyl ions. Covalent hydrolysis differs from the cracking of hydrocarbons in that the former is a reaction with water to form smaller saturated molecules, while the latter is a splitting of saturated molecules to form unsaturated molecules. Thus carbohydrates, such as cellulose and starch, may be split to form smaller carbohydrate molecules such as the simple sugars; and proteins may be split in a stepwise fashion into a series of products, ending in simple amino acids. Digestion is largely a process of splitting large molecules into smaller molecules that can be absorbed and used in the body to build new large molecules.

Chain Hydrocarbons May Also Be Polymerized.

Polymerization is the opposite of cracking; that is, *it is the building of large molecules from small molecules*. Gasoline and other hydrocarbon products may be prepared by the polymerization of gaseous hydrocarbons.

It is thought that carbohydrates are produced in nature by a polymerization of formaldehyde, CH_2O. Thus six molecules of formaldehyde would polymerize to form $C_6H_{12}O_6$, a simple sugar. Still larger molecules of starches and celluloses would be formed by a continuation of the process.

Rubber may be formed by the polymerization of hydrocarbons found in turpentine.

Plastics are produced by polymerization reactions.

Unsaturated Hydrocarbons and Even Carbon Itself May Be Hydrogenated.

Hydrogenation is a process in which hydrogen is added to carbon or its unsaturated compounds. Thus vegetable oils, such as cottonseed, peanut, and olive oils, and animal oils, such as fish oil, may be changed to solid fats by hydrogenation. This is possible because the oils are

unsaturated compounds and the corresponding saturated compounds produced by hydrogenation are fats.

Coal may be hydrogenated to produce gasoline, and this process is now being carried out on a large scale in certain European countries.

The Majority of Organic Reactions Are Substitution Reactions.

If methane is treated with chlorine under properly controlled conditions, one or more of the hydrogen atoms may be replaced with chlorine atoms. Thus:

$\begin{array}{c} \mathrm{H} \\ \mid \\ \mathrm{H—C—H} \\ \mid \\ \mathrm{H} \end{array}$	$\begin{array}{c} \mathrm{H} \\ \mid \\ \mathrm{H—C—Cl} \\ \mid \\ \mathrm{H} \end{array}$	$\begin{array}{c} \mathrm{H} \\ \mid \\ \mathrm{H—C—Cl} \\ \mid \\ \mathrm{Cl} \end{array}$	$\begin{array}{c} \mathrm{Cl} \\ \mid \\ \mathrm{H—C—Cl} \\ \mid \\ \mathrm{Cl} \end{array}$	$\begin{array}{c} \mathrm{Cl} \\ \mid \\ \mathrm{Cl—C—Cl} \\ \mid \\ \mathrm{Cl} \end{array}$
methane, a cheap fuel gas	methyl chloride, a refrigerant	methylene dichloride, a cleaning solvent	chloroform, an anaesthetic	carbon tetrachloride, a fire-extinguisher and cleaning solvent

By appropriate reactions (with sodium hydroxide for example)

$$\begin{array}{c} \mathrm{H} \\ \mid \\ \mathrm{H—C—Cl} \\ \mid \\ \mathrm{H} \end{array} \text{ may be changed to } \begin{array}{c} \mathrm{H} \\ \mid \\ \mathrm{H—C—OH} \\ \mid \\ \mathrm{H} \end{array} \text{ which is methyl alcohol.}$$

Methyl alcohol may also be prepared by the hydrogenation of carbon monoxide:

$$\mathrm{CO} + 2\,\mathrm{H_2} \longrightarrow \begin{array}{c} \mathrm{H} \\ \mid \\ \mathrm{H—C—OH} \\ \mid \\ \mathrm{H} \end{array}$$

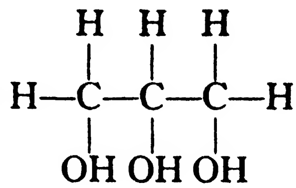
Alcohols are hydroxyl derivatives of hydrocarbons.

$$\text{Ethyl alcohol } \begin{array}{c} \mathrm{H\;\;H} \\ \mid\;\;\mid \\ \mathrm{H—C—C—OH} \\ \mid\;\;\mid \\ \mathrm{H\;\;H} \end{array}$$

Next to water, ethyl alcohol is the most important solvent.

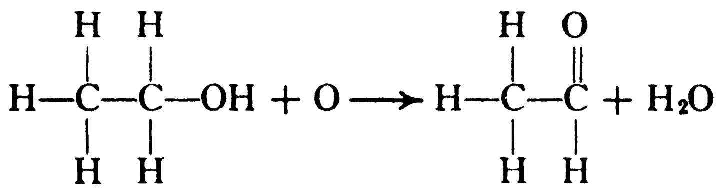
$$\text{Ethylene glycol } \begin{array}{c} \mathrm{H\;\;H} \\ \mid\;\;\mid \\ \mathrm{H—C—C—H} \\ \mid\;\;\mid \\ \mathrm{OH\;OH} \end{array}$$

Ethylene glycol is used as an antifreeze in automobile radiators.

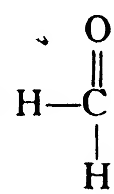
Glycerol 

Glycerol, known under its common name, glycerine, is used to make nitroglycerine, an explosive.

Aldehydes are produced by the oxidation of alcohols in which two atoms of hydrogen are removed.

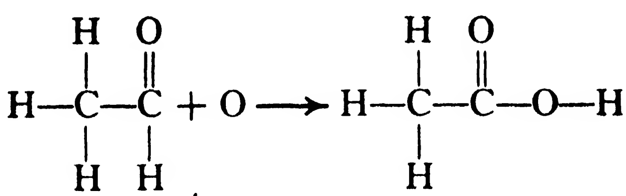


ethyl alcohol acetaldehyde

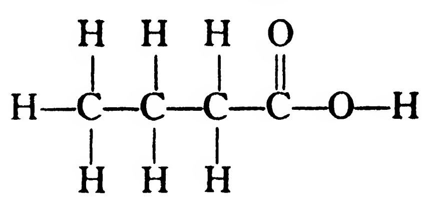
Formaldehyde 

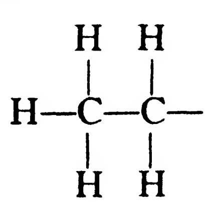
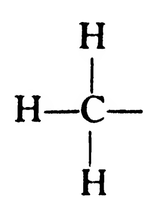
is the most common aldehyde. It is used as a disinfectant and preservative and in the manufacture of plastics.

Organic acids may be considered to be derivatives of hydrocarbons in which the H is substituted by a carboxyl group, COOH, or as products obtained by the oxidation of aldehydes, thus:



acetic acid
(the acid in vinegar)

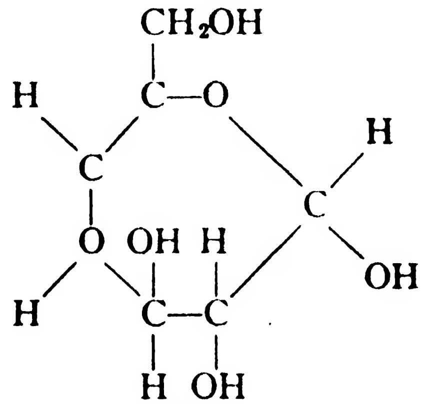
Acetic acid and butyric acid, , an acid in rancid butter, are typical organic acids.

Such groups of atoms as  or  act as units and are therefore called hydrocarbon radicals. They are usually written as C_2H_5, CH_3, etc.

An *ether* is an oxide of hydrocarbon radicals; diethyl ether is $(C_2H_5)_2O$.

A *ketone* consists of two hydrocarbon radicals joined to a carbonyl radical, CO. Acetone, the varnish solvent and paint remover, is $(CH_3)_2C{=}O$.

Carbohydrates (sugars, starches, celluloses, etc.) are chain hydrocarbons in which alcohol radicals, OH, and aldehyde radicals, $\overset{\displaystyle O}{\overset{\|}{C}}{-}H$, or ketone radicals, $C{=}O$, have replaced some of the hydrogen atoms; for example:



glucose

Esters are compounds formed by the action of organic acids with alcohols.

$$\underset{\text{acetic acid}}{CH_3COOH} + \underset{\text{ethyl alcohol}}{C_2H_5OH} \longrightarrow \underset{\text{ethyl acetate}}{CH_3COOC_2H_5} + \underset{\text{water}}{H_2O}$$

Fats are esters formed by the action of the alcohol, glycerol, with certain organic acids. When fats are treated with strong inorganic bases such as sodium hydroxide, the metal of the base replaces the glycerol radical, which combines with the hydroxyl group, OH, of the base to form glycerol. The metallic salt of the acid which is thus produced is called a *soap*, and the reaction by which the soap is thus produced is called *saponification*.

Proteins consist of long chains or networks of *amino acids* joined one to another. An amino acid is an organic acid in which one of the hydrogen atoms of a hydrocarbon radical has been replaced by an amino group, NH_2.

$$\underset{\text{acetic acid}}{CH_3COOH} \qquad \underset{\text{aminoacetic acid}}{CH_2NH_2COOH}$$

Amines are amino derivatives of hydrocarbons:

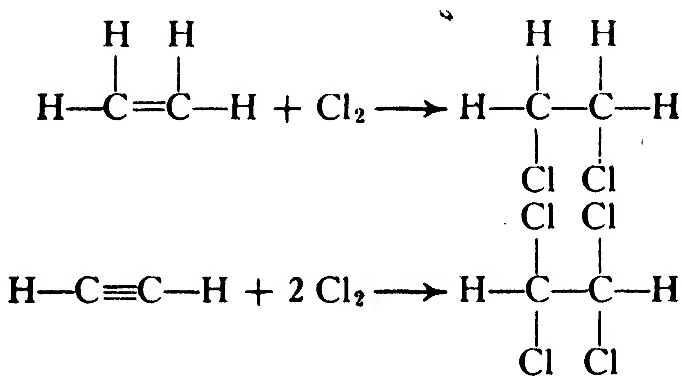
$$\underset{\text{ethylamine}}{C_2H_5NH_2} \qquad \underset{\text{methylamine}}{CH_3NH_2}$$

Unsaturated Hydrocarbons Permit Addition Reactions as Well as Substitution Reactions.

There are many possible unsaturated hydrocarbons, inasmuch as one or more double or triple bonds may be introduced into the chains.

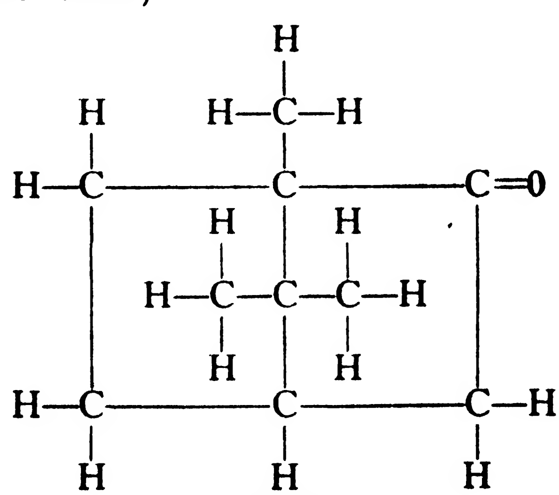
Ethylene, H—C=C—H, is the simplest hydrocarbon with a double bond. It is now used as an anaesthetic, fruit ripener and colorer, and celery bleacher. Acetylene, H—C≡C—H, is the simplest hydrocarbon with a triple bond. Because of its triple bond, it is very active, and it is used in the synthesis of many other products, as well as in acetylene lights and welding.

Ethylene or acetylene will add on chlorine directly:

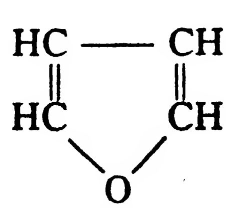


Carbon Also Forms Ring Hydrocarbons.

There are many kinds of cyclic hydrocarbons and their derivatives, such as camphor and furan,



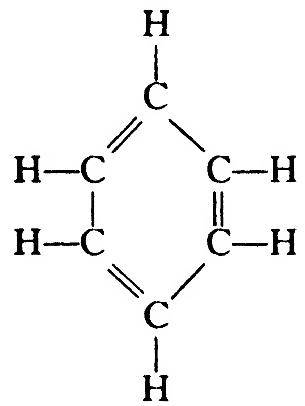
Camphor



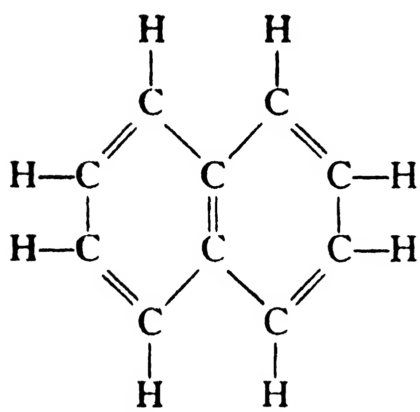
Furan

but the most important ringlike compounds are those which contain six carbon atoms.

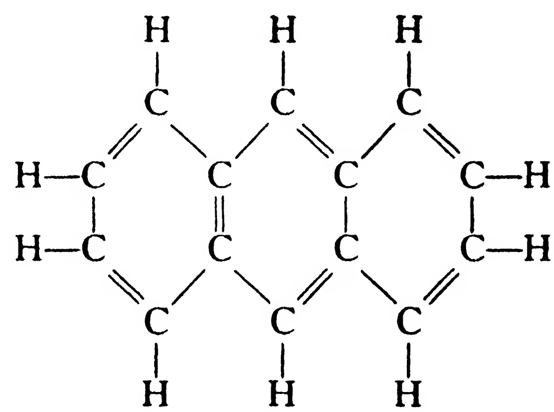
When coal tar is distilled, a number of ring hydrocarbons are separated. These include:



Benzene



Naphthalene

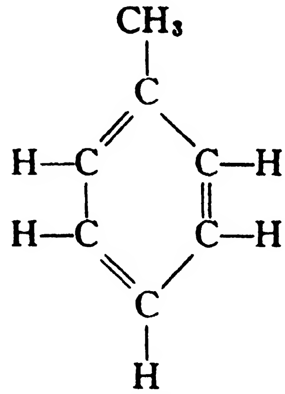


Anthracene

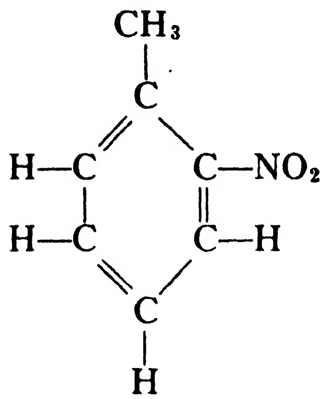
Many other ring compounds are known. Their ringlike structures make their properties somewhat different from the properties of the chain compounds, and thus two broad fields of organic chemistry are recognized. *Aliphatic chemistry is the study of the chain hydrocarbons and their derivatives; aromatic chemistry is the study of the ring hydrocarbons and their derivatives.*

Ring hydrocarbons are unsaturated, but their structure makes it more difficult for them to form addition products than it is for the unsaturated chain compounds. Ring hydrocarbons form many derivatives by substitution. Some of the most important derivatives of benzene will be discussed in the next Unit. Because of their ring structure, ring hydrocarbons are not readily cracked or polymerized.

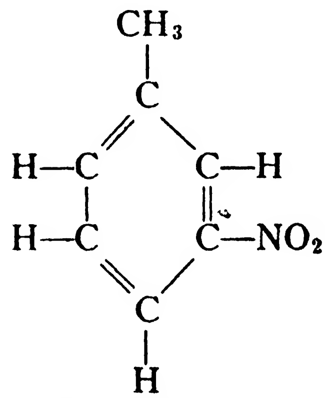
An important type of isomerism characteristic of the aromatic hydrocarbons may be called *positional* isomerism; for example, the properties of the nitro, NO_2, derivatives of toluene depend upon which carbon atoms they are attached to.



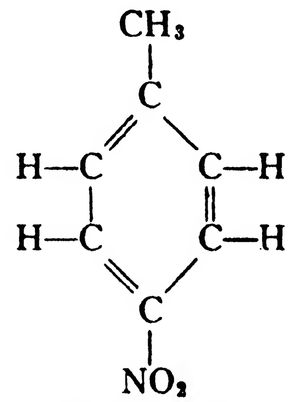
Toluene



Ortho-nitrotoluene
(Ortho position)



Meta-nitrotoluene
(Meta position)



Para-nitrotoluene
(Para position)

A patent attorney explained positional isomerism to a judge as follows:

> Your Honor, the question of substituents is like the turtle. As Your Honor knows, the ordinary turtle has his head opposite his tail and he is therefore a para-turtle. If he were deformed by having his tail where a fore-leg is, he would be an ortho-turtle, while if his tail replaced a hind leg, he would be a meta-turtle. As reptiles they would not be alike.[1]

STUDY QUESTIONS

1. Why is the number of organic compounds so large?
2. What is a *hydrocarbon?*
3. Name three important series of hydrocarbons and give their origin.
4. What is meant by *cracking* of hydrocarbons?
5. Differentiate between saturated and unsaturated compounds.
6. Give several examples of polymerization.
7. What is meant by *hydrogenation?* Give several examples.
8. Show how hydrocarbons, alcohols, aldehydes, and acids are related.
9. What does the field of aromatic chemistry include?
10. Are the majority of organic compounds electrovalent or covalent in nature?
11. Why do the majority of organic chemical reactions take place slowly?
12. What is meant by the term *esterification?*
13. What is an amine?

[1] *News Edition, Industrial and Engineering Chemistry,* 1940, p. 465.

14. What is an amino acid?
15. What is the nature of a protein?
16. What is a fat?
17. How is a soap made from a fat? What is the process called? What by-product is obtained in this process? What is a soap?
18. What is polymerization?
19. What group is characteristic of ketones?
20. What is an ether?
21. What four compounds may be prepared by the action of chlorine on methane?
22. What is meant by ortho, meta, and para aromatic compounds?

UNIT IX

CREATIVE CHEMISTRY HAS CONTRIBUTED GREATLY TO MAN'S PHYSICAL PROGRESS

INTRODUCTION TO UNIT IX

Chemistry plays a vital part in man's mastery of his material world, because, as we learned in a previous unit, it is the science which deals with the transformations of matter. It is the purpose of this Unit not only to provide an appreciation of the accomplishments of chemistry in producing better things for better living but also to show how essential chemical research is to the success of industry in this modern world. The picture to be presented is very incomplete because, in every field of science, the story of accomplishment always leads to unsolved problems. Chemistry is a growing, maturing science. It is bringing profound changes to man's way of living. No one can understand the impact of Science on civilization or be prepared to make an intelligent adjustment to these changing conditions without an appreciation of what chemistry has done and is doing to provide for old necessities and to create new necessities of life.

What are the raw materials used to produce "better things for better living"? What are the raw materials which are increasing in their importance in the synthesis of materials unlike any ever found in nature? To what extent is the United States endowed with essential raw materials? To what extent should we be concerned about the conservation of these raw materials? Such are some of the vital topics considered in this Unit.

UNIT IX

SECTION 1

OXYGEN AND SULFUR, CARBON AND SILICON ARE IMPORTANT ELEMENTS IN NATURE'S CHEMICAL STOREHOUSE

Introduction.

Two pairs of nonmetals, representing two families of the periodic table, namely, oxygen and sulfur, carbon and silicon, are very abundant, cheap raw materials, whose increasing use is so modifying our environment that they may be used as yardsticks for gauging the extent of the industrialization of modern civilization. Silicon is the only one of these elements that does not occur in large amounts in the uncombined state. Free silicon has few uses, but the compounds of silicon, such as sand, gravel, clay, and stone, rank next to coal in the tonnage of their production.

A recent study has shown that water, air, coal, and sulfur are needed most frequently in preparing the 150 most important heavy (bulk) chemicals used in modern industry.

Oxygen Is the Most Abundant Raw Material.

Among all the elements oxygen stands first in abundance. Not only is oxygen found in the atmosphere in the free state to the extent of about 21 per cent by volume, but it is also found in the combined state as water, H_2O, sand, SiO_2, and in the majority of the materials which make up the earth's crust. Nearly two thirds of the human body is oxygen. Oxygen constitutes about 50 per cent of all of the known material of our world, including its atmosphere, hydrosphere, and lithosphere.

For commercial purposes the air generally serves as a source of oxygen, inasmuch as the other gases in the atmosphere are inert. When relatively pure oxygen is needed, it may be prepared by the fractional distillation of liquid air, while still purer oxygen is obtained by the electrolysis of water. Air and water are the two most important industrial raw materials. Oxygen is referred to as the "breath of industry."

The use of oxygen in combustion is discussed in Section 4 of this Unit. The most important commercial use of oxygen is in the production of high temperatures with hydrogen or acetylene in blowpipes, which have given industry quick methods, which work even under water, for cutting and welding metals. Metal surfaces are descaled in preparation for painting by heating the surface with oxyacetylene torches.

Smaller amounts of oxygen are used in the treatment of such diseases as pneumonia in which the patient cannot inhale sufficient air to supply the oxygen requirements of the body. Oxygen cylinders are carried by miners when entering mines containing poisonous gases and by aviators to supply oxygen for breathing at high altitudes. Oxygen, O_2, may be converted into ozone, O_3, by passing the oxygen between two plates highly charged with electricity. Oxygen and ozone are examples of *allotropic forms of elements, i.e., forms of elements differing in energy content, and, therefore, differing in crystalline structure and in physical properties.*

Ozone is a powerful oxidizing agent and is used, therefore, as a bleaching agent, as a disinfectant, and a deodorizer. Air and water may be purified by ozone. Care must be taken not to inhale even small quantities of ozone because it is harmful to the body.

Oxygen is the most important nonmetal. Sulfur belongs to the periodic family headed by oxygen and resembles it chemically, forming many similar compounds:

PbO	FeO	H_2O	CO_2	$(C_2H_5)_2O$
PbS	FeS	H_2S	CS_2	$(C_2H_5)_2S$

Sulfur Is the Cornerstone of Chemical Industry.

The Lord rained upon Sodom and upon Gomorrah, brimstone and fire from the Lord out of Heaven. — Genesis 20:24.

Upon the wicked he shall rain snares, fire and brimstone. — Psalms 11:6.

The ancient Hebrews were evidently quite familiar with the properties of sulfur (brimstone) which occurs in volcanic deposits in the Mediterranean region. They undoubtedly knew that sulfur burns readily, evolving vile, choking fumes. *Harry N. Holmes* ("Out of the Test Tube," Emerson Books, Inc.) tells how brimstone of the ancients has become the cornerstone of modern chemical industry. Sulfur owes its chief importance in chemical industry to the fact that it is the raw material from which sulfuric acid, the "work horse" of chemistry, is manufactured.

Sulfur Is One of the Cheapest Raw Materials. Sulfur is very widely distributed in nature and constitutes about 0.06 per cent of the earth's

crust. It is an essential element in the molecules of some proteins. Sulfur occurs in large quantities in the form of sulfides of iron, copper, zinc, and lead and sulfates of calcium and magnesium. It is estimated that the oceans contain eleven hundred trillion tons of dissolved sulfates. In the uncombined state sulfur occurs in the vicinities of hot springs and volcanoes, where it was probably deposited by the interaction of the sulfurous gases of these regions as follows:

$$\underset{\text{hydrogen sulfide}}{2\,H_2S} + \underset{\text{sulfur dioxide}}{SO_2} \longrightarrow \underset{\text{water}}{2\,H_2O} + \underset{\text{sulfur}}{2\,S}$$

or by the decomposition or oxidation of the hydrogen sulfide formed from underground deposits of metallic sulfides by still different reactions.

Large sedimentary beds of sulfur, which are always closely associated with gypsum and limestone, are thought to have been formed by the action of carbon compounds on gypsum, $CaSO_4$, to form limestone, $CaCO_3$, and sulfur. Over 95 per cent of the world's production of sulfur comes from these sedimentary deposits, the most important of which occur in Sicily and the Gulf Coast of the United States.

It is estimated that over 30,000,000 tons of sulfur have been mined in Sicily, which supplied the world with sulfur for five hundred years. Today the Sicilian deposits account for only 12 per cent of the world's production of sulfur because *Herman Frasch* devised an economical process to obtain sulfur from the world's largest sulfur deposits in the Gulf States, which occur in beds lying from 500 to 1500 feet below the surface. Shaft mining failed here because of the nature of the ground and the presence of the poisonous gas, hydrogen sulfide.

In 1891 *Herman Frasch* patented his process to remove sulfur from these deposits by forcing superheated water into the sulfur beds to melt the sulfur, which is then raised to the surface by compressed air.

Since 1903, when the Frasch process was finally perfected, 45,000,000 tons of sulfur have been produced in the United States.

This economical process produces sulfur of a purity of 99.5 per cent, which can be stored in the open without loss.

Sulfur Is One of the Five Basic Raw Materials of Chemical Industry. Salt, coal, limestone, sulfur, and water have long been considered to be the five basic raw materials of chemical industry. Eight per cent of the sulfur mined is burned with air to produce sulfur dioxide, which is used extensively for producing wood pulp, for bleaching, for the treatment of fruits to prevent oxidation and bacterial action, as a refrigerant, and for the preparation of sulfuric acid.

In the preparation of sulfuric acid, sulfur dioxide must be changed

to sulfur trioxide, which then reacts with water to produce sulfuric acid.

$$\underset{\text{sulfur dioxide}}{2\,SO_2} + \underset{\text{oxygen}}{O_2} \longrightarrow \underset{\text{sulfur trioxide}}{2\,SO_3}$$

$$\underset{\text{sulfur trioxide}}{SO_3} + \underset{\text{water}}{H_2O} \longrightarrow \underset{\text{sulfuric acid}}{H_2SO_4}$$

When sulfur is burned in air, only sulfur dioxide is produced. A catalyst (see Section 5 of this Unit), *i.e., an added material which, by its mere presence, changes the rate of a chemical reaction*, must be employed to add an extra oxygen to sulfur dioxide to form sulfur trioxide. In the "lead chamber" process the catalyst consists of oxides of nitrogen; in the contact process the catalyst consists of finely divided platinum or other materials. Because sulfuric acid is a heavy, oily liquid and was formerly prepared from vitriol, it is called "oil of vitriol," and its salts are called "vitriols"; for example, copper sulfate is called "blue vitriol."

Sulfuric acid is so important in modern industry that its production is one of the best indexes of industrial prosperity in general. The annual production of sulfuric acid is about 7,000,000 tons. Sulfuric acid is the cheapest and most satisfactory acid for many purposes. Large quantities of sulfuric acid are used in the treatment of phosphate rock, which is insoluble in water, to produce calcium superphosphate, which is soluble in water, for use in fertilizers. Its reactivity with unsaturated compounds is applied in the refining of petroleum; and its great affinity for water makes it useful in reactions in which nitric acid is used to nitrate such material as cellulose or toluene, because these reactions will not go to completion unless the water is removed as rapidly as it is produced.

$$\underset{\text{toluene}}{C_6H_5CH_3} + \underset{\text{nitric acid}}{3\,HNO_3} \longrightarrow \underset{\text{T.N.T.}}{C_6H_2(NO_2)_3CH_3} + \underset{\text{water}}{3\,H_2O}$$

Sulfuric acid has such a great affinity for water that it will extract water from carbohydrates, leaving carbon as a residue. Because of this property, clothing and the skin of laboratory workers must be protected against sulfuric acid. The low volatility of sulfuric acid makes possible its use in the preparation of the other, more volatile acids. For example:

$$\underset{\text{sodium nitrate}}{2\,NaNO_3} + \underset{\text{sulfuric acid}}{H_2SO_4} \longrightarrow \underset{\text{nitric acid}}{2\,HNO_3} + \underset{\text{sodium sulfate}}{Na_2SO_4}$$

$$\underset{\text{sodium chloride}}{2\,NaCl} + \underset{\text{sulfuric acid}}{H_2SO_4} \longrightarrow \underset{\text{hydrochloric acid}}{2\,HCl} + \underset{\text{sodium sulfate}}{Na_2SO_4}$$

The acid properties of sulfuric acid find wide application in cleaning scale from iron and steel. This process is called "pickling." Everyone is familiar with the use of sulfuric acid in lead storage batteries.

Old-fashioned gunpowder was a mixture of sulfur, charcoal, and saltpeter. Sulfur, dissolved in lime and water to form lime-sulfur spray or in the powdered form, is used to check scale and fungus enemies in agriculture. Sulfur is used in the manufacture of fireworks, matches, paints, rubber, plastics, and hundreds of other materials.

The Utilization of Waste Sulfur Dioxide Constitutes an Important Conservation Problem.

About one fifth of the sulfuric acid is manufactured from the waste gases of smelters in which metallic sulfides are *roasted, i.e., heated in the presence of air to change them into oxides.* Pyrite, FeS_2, may be burned to produce sulfur dioxide, and it is used for the manufacture of sulfuric acid where it can be obtained more cheaply than sulfur. Over one half of the production of sulfuric acid in the United States could be taken care of by the gases which are still wasted in the western smelters. This loss is a crime from the point of view of conservation, but our present economic system is so organized that it is not financially advantageous to conserve these gases. Here is another challenge to the ability of a democracy to conserve its resources. Is this a job for the government or can it be handled by private initiative and research?

Coal is produced from plant materials, the protein of which contains sulfur. Some coals contain as high as 5 per cent sulfur. Large cities which use coal as a fuel are deluged by large quantities of sulfur dioxide, which acts on stone, metals, wood, and textiles. Wearing apparel quickly wears out in these regions because of their daily acid bath produced by the reaction of sulfur dioxide with moisture. How can these sulfurous fumes be kept out of the air of our large cities? This is now an economic problem that remains to be solved.

Carbon, in Its Several Forms, Is Another Important Industrial Raw Material.

The utilization of coal, petroleum, and natural gas as sources of important organic compounds is discussed in Sections 8 and 9 of this Unit. The discussion of carbon in this Unit will be restricted to elemental carbon and its inorganic compounds.

Carbon occurs in nature in the two crystalline allotropic forms, graphite and diamond, and as amorphous carbon.

"Life Would Be Rather Dull without Graphite, although the Material Itself Is One of the Dullest of All Substances."[1]

Graphite is widely used in "lead" pencils and as a lubricant, stove polish, and paint pigment because of its soft, greasy, chemically inert properties. It is an electrical conductor and is therefore used to make electrodes for dry cells and electric furnaces, commutator brushes for generators, and in making electrotypes for printing. Because of its inertness and resistance to high temperatures, it is used to make refractory bricks and crucibles.

Graphite may be prepared by heating anthracite coal in an electric furnace. Prepared in this way, graphite is generally superior to naturally occurring graphite.

The Diamond Is the Hardest Substance Known.

The highly crystalline, colorless, transparent properties of pure diamonds cause them to be highly prized as gems, but it is the great hardness of diamonds that makes them of importance in industry in providing a cutting edge for core drills and for grinding purposes. Diamonds which contain impurities which discolor them, sometimes almost black, are used for industrial purposes. Artificial diamonds of small size have been made by crystallizing carbon in cast iron, but no diamonds have been produced which are large enough for use as gems.

Amorphous Forms of Carbon Vary According to Their Methods of Preparation.

Anthracite Coal Is Nearly Pure Carbon. Coal is produced by changes in plant matter, and anthracite coal is the product in which these changes have gone the farthest. The various stages in the decomposition of plant materials (chiefly cellulose) are represented by peat, lignite, bituminous coal (soft coal), and anthracite coal (hard coal).

Anthracite is a very desirable fuel because it burns with the production of the maximum amount of heat and the minimum amount of smoke and sulfurous fumes. Only about 0.65 per cent of the coal resources of the United States are of the anthracite variety. At the present rate of consumption our anthracite coal resources will be exhausted in about one hundred years.

Coke Is Obtained by Heating Bituminous Coal in the Absence of Air. When bituminous coal is heated in the absence of air, fuel gases (artificial gas), ammonia, and coal tar are important materials which are driven off from the coal, leaving the mineral matter and carbon in

[1] C. C. Furnas, *The Storehouse of Civilization*, Columbia University Press, New York, 1939, p. 144.

a porous form, called "coke." Coke is also obtained in the refining of petroleum. Coke, like anthracite coal, is an excellent fuel, but it is used chiefly as a reducing agent in the refining of metals, especially iron, and in the production of inorganic carbon compounds.

The combustion of coke provides heat to decompose limestone, carbon dioxide and lime being produced in the reaction:

$$\underset{\text{oxygen (air)}}{O_2} + \underset{\text{coke}}{C} + \underset{\text{limestone}}{CaCO_3} \longrightarrow \underset{\text{lime}}{CaO} + \underset{\text{carbon dioxide}}{2\ CO_2}$$

Coke reacts with steam to produce the important industrial fuel, water gas.

$$\underset{\text{coke}}{C} + \underset{\text{steam}}{H_2O} \longrightarrow \underbrace{\underset{\text{hydrogen}}{H_2} + \underset{\text{carbon monoxide}}{CO}}_{\text{water gas}}$$

Producer gas is a similar fuel containing nitrogen in addition to hydrogen and carbon monoxide, because it is prepared by heating bituminous coal with a mixture of air and steam.

When heated to a high temperature, coke will combine with sulfur to produce carbon disulfide, CS_2, an evil-smelling, inflammable liquid with many large-scale industrial uses.

Coke and lime react in an electric furnace to produce calcium carbide.

$$\underset{\text{lime}}{CaO} + \underset{\text{coke}}{3\ C} \longrightarrow \underset{\text{calcium carbide}}{CaC_2} + \underset{\text{carbon monoxide}}{CO}$$

Calcium carbide is extremely important because it will react with water to furnish acetylene, which is used not only in oxyacetylene welding but also as a starting-point in the synthesis of many organic compounds, which will be mentioned in later sections in this Unit.

$$\underset{\text{calcium carbide}}{CaC_2} + \underset{\text{water}}{H_2O} \longrightarrow \underset{\text{lime}}{CaO} + \underset{\text{acetylene}}{C_2H_2}$$

Calcium carbide will also combine with nitrogen to form calcium cyanamide:

$$\underset{\text{calcium carbide}}{CaC_2} + \underset{\text{nitrogen}}{N_2} \longrightarrow \underset{\text{calcium cyanamide}}{CaCN_2} + \underset{\text{carbon}}{C}$$

Calcium cyanamide will react with water to produce ammonia, and it therefore serves as a good source of nitrogen for fertilizers.

When coke is heated with sand in an electric furnace, silicon carbide (carborundum) is produced.

$$\underset{\text{sand}}{SiO_2} + \underset{\text{coke}}{3\ C} \longrightarrow \underset{\text{silicon carbide}}{SiC} + \underset{\text{carbon monoxide}}{2\ CO}$$

Silicon carbide is almost as hard as the diamond and is much used as an abrasive. Two other crystalline materials closely approaching the diamond in hardness are tungsten carbide, WC_2, well known as *carboloy*, and tantalum carbide, known as *tantaloy*, which are used in cutting-tools.

Charcoal Is Obtained by Heating Wood in the Absence of Air. In heating wood, as in heating bituminous coal, many valuable by-products such as acetic acid, acetone, and wood alcohol are obtained from the gases which are driven off from the wood, leaving the minerals and carbon in the form of charcoal. This process is called *destructive distillation*. Coke is only about 89 per cent carbon, while charcoal is about 97 per cent carbon.

Charcoal is used where relatively pure forms of carbon are needed in the reduction of metals, such as in the production of crucible steel.

Animal charcoal (bone black) is obtained by the destructive distillation of bones. Certain types of charcoal, especially bone black, have excellent adsorptive properties and are used in the refining of sugar to remove soluble coloring materials. This adsorptive property of charcoal may be increased by "activating" it, *i.e.*, heating it under controlled conditions. Activated charcoal is used in gas masks to remove poisonous gases from the air and in extracting gasoline from natural gas.

Carbon Black and Lampblack Are Formed by Cracking Fuel Gases. When a natural-gas flame is directed against a cold metal surface, a black, fluffy, finely divided powder, called "carbon black," is produced. Lampblack is a similar material produced by burning fuel gases in a supply of air insufficient to completely oxidize them. Lampblack will deposit on cooking utensils when they are placed over a yellow gas flame, which is the result of an improper mixture of air with the natural gas in the burner. In one large nitrogen-fixation plant, natural gas is heated to obtain hydrogen, the carbon, in this case, being a by-product.

$$\underset{\text{methane}}{CH_4} \longrightarrow \underset{\text{carbon}}{C} + \underset{\text{hydrogen}}{2\,H_2}$$

Carbon black and lampblack are used to add strength and resiliency to rubber tires and in the preparation of inks, paints, shoe polish, phonograph records, and black concrete.

Silicon, the Second Most Abundant Element, Is the Inorganic Counterpart of Carbon.

It is estimated that about 27 per cent of the lithosphere consists of silicon in the form of its compounds. Silicon never occurs free in nature. Just as carbon compounds are the basis of the organic world, so silicon compounds are the basis of the inorganic world. All varieties

of granite, sandstone, shale, clay, gneiss, and marl are silicates. The only important rocks not siliceous in nature are limestone, $CaCO_3$, and dolomite, $MgCO_3$.

Silicon can be obtained in the form of crystals which resemble the diamond by the reduction of silicon dioxide with aluminum.

Silicon will react with sodium hydroxide to form soluble silicates and hydrogen. This reaction was used in the World War of 1914–1918 to produce hydrogen for observation balloons.

Silicon Is a Member of the Carbon Family.

Silicon forms many compounds which are similar to the corresponding carbon compounds.

CO	CH_4	CCl_4	CO_2	Na_2CO_3	$CHCl_3$
SiO	SiH_4	$SiCl_4$	SiO_2	Na_2SiO_3	$SiHCl_3$

For example, SiH_4 is a colorless, combustible gas which resembles methane, CH_4.

Silicon combines with chlorine to form silicon tetrachloride, $SiCl_4$, which hydrolyzes in contact with the moisture in the air to form an oxide or hydroxide of silicon. This reaction has been used to produce smoke screens for warfare.

Silicon dioxide (silica) occurs in such forms as quartz, sand, chalcedony, amethyst, onyx, jasper, opal, agate, and flint.

Fused silica is resistant to chemical action and has a very small coefficient of expansion. Silica has such a very high melting-point that it is difficult to fashion utensils from it. Some forms of "Pyrex" glass are nearly pure silica. In addition to its use in the preparation of Portland cement and ceramic materials, discussed in Section 4 of this Unit, and its use to prepare carborundum, silica is chiefly used to prepare water glass and silica gel.

Water glass is a mixture of soluble silicates, which may be prepared by any one of the following reactions:

$$\underset{\text{sodium carbonate}}{Na_2CO_3} + \underset{\text{silica}}{SiO_2} \longrightarrow \underset{\text{sodium silicate}}{Na_2SiO_3{}^1} + \underset{\text{carbon dioxide}}{CO_2}$$

$$\underset{\text{sodium sulfate}}{Na_2SO_4} + \underset{\text{silica}}{SiO_2} \longrightarrow \underset{\text{sodium silicate}}{Na_2SiO_3} + \underset{\text{sulfur trioxide}}{SO_3}$$

$$\underset{\text{sodium hydroxide}}{4\ NaOH} + \underset{\text{silica}}{SiO_2} \longrightarrow \underset{\text{sodium silicate}}{Na_4SiO_4{}^1} + \underset{\text{water}}{2\ H_2O}$$

Water glass forms a thick, syrupy liquid that is widely used as an adhesive in joining sheets of paper to form paper boards, as a builder in soaps, in waterproofing plaster or cement, and in fireproofing wood and other inflammable materials.

[1] Na_2SiO_3 and Na_4SiO_4 are typical soluble silicates found in water glass.

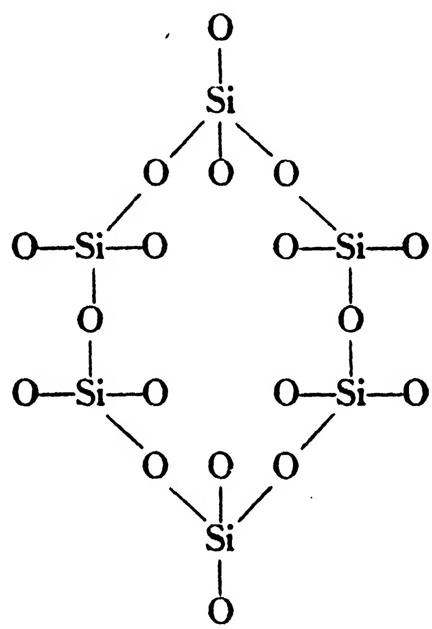
A gel is formed when sodium silicate is acted upon by an acid.

$$\underset{\text{sodium silicate}}{Na_4SiO_4} + \underset{\text{sulfuric acid}}{2\,H_2SO_4} \longrightarrow \underset{\text{silicic acid}}{H_4SiO_4} + \underset{\text{sodium sulfate}}{2\,Na_2So_4}$$

When silicic acid is partially dehydrated, it produces a very finely divided material called "silica gel," which is widely used in industry as an adsorbent and catalytic agent.

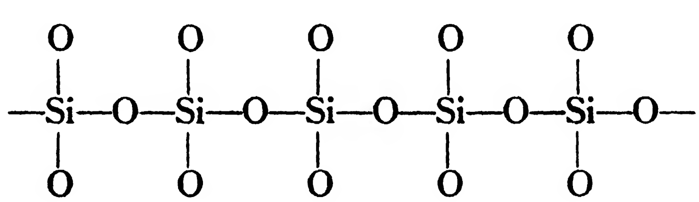
Like carbon, silicon forms a great many compounds because it has both a positive and negative valence of four and may thus form complex chains and rings containing many silicon atoms.

Many natural silicates owe their complexity to their complex crystal structures built up of alternate silicon and oxygen atoms. Thus the ring

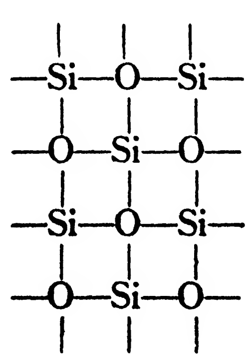


is present in beryl, $Be_3Al_2Si_6O_{18}$.

Fibers such as asbestos, $CaMg_3(SiO_3)_4$, are formed from silicon-oxygen chains:



Sheets such as mica, $H_2Kl_3(SiO_4)_3$, are formed from an arrangement such as



A new, fireproof, transparent film was produced in 1938 by drying a jelly made by mixing bentonite clay with water. These films are made transparent by the application of pressure. They are flexible, electrically insulating, and resistant to chemicals. Undoubtedly bentonite films will find many useful applications in industry and commerce.

Feldspars such as $NaAlSi_3O_8$ consist of three-dimensional networks of oxygen and silicon atoms.

STUDY QUESTIONS

1. Sulfur is a very poor conductor of heat and electricity, resists wetting by water, may be readily melted, and is fairly strong. Can you suggest any possible uses which take advantage of the above properties of sulfur?
2. In what respects does sulfur resemble oxygen?
3. In what respects does silicon resemble carbon?
4. Account for the large number and the complexity of the compounds of silicon.
5. Why is oxygen called "the breath of industry"?
6. Considering how active oxygen is, how would you account for so much free oxygen in the atmosphere?
7. How is industrial oxygen prepared?
8. What are allotropic forms? Give examples of the two elements discussed in this Section which occur as allotropic forms.
9. What is the outstanding property of the diamond?
10. Account for the large beds of sulfur.
11. Describe the Frasch process of mining sulfur.
12. Discuss the occurrence, preparation, and uses of the different forms of carbon.
13. Discuss the preparation, properties, and uses of sulfuric acid.
14. How do you account for the presence of sulfur in coal?
15. Discuss the properties and uses of graphite.
16. Account for the different varieties of coal.
17. Why has coal production decreased during the past decade?
18. What important materials may be obtained from coke?
19. What is meant by destructive distillation? Illustrate with an example.
20. How is silica gel prepared, and for what purposes is it used?
21. How is water glass prepared, and for what is it used?

UNIT IX

SECTION 2

METALLURGICAL PROCESSES HAVE MADE POSSIBLE THIS AGE OF METALS

Introduction.

The use of coal to replace charcoal in the smelting of iron and the invention of the steam engine inaugurated the industrial revolution. Our modern industrial civilization is still based on iron, and every year has witnessed new methods of producing harder, tougher, and stronger iron alloys (steels). Up until recent times the corrosion of iron nearly kept pace with its extraction from ores, but modern research has developed many corrosion-resistant alloys and other methods of combating corrosion.

New metals and alloys have entered industry in competition with steel. Chief among these new metals is aluminum, the most widely distributed and most abundant metal, though practically unknown until the twentieth century because of the highly specialized means required for its extraction. Suitably alloyed and treated, aluminum has properties rivaling those of mild steel. One of the trends in modern metallurgy is toward lighter alloys.

Every year sees fresh progress in the field of metallurgy, and there is hardly any branch of the history of civilization more fascinating than that which traces the development of man from the Stone Age to the Metal Age of today.

Progress in Metallurgy Has Depended on the Widespread Use of Metals.

Metallurgy is the science and art of preparing metals for use from their ores. The metallurgical processes depend upon the nature of the ore and the metal to be separated. The metallurgy of the heavy metals differs in general from that of lighter ones.

The metallurgical operations (often called smelting) of the heavy metals fall into four groups: (1) The ore is separated from useless foreign material by various *concentration* methods. This is done by hand selection, sifting, washing with a stream of water, and froth

flotation. Many improved types of concentrating machinery have made it possible to reopen abandoned mines, and to run them at a profit. (2) After concentration, many ores need to be *roasted* — that is, heated in an excess of air — to convert compounds of sulfur and arsenic into oxides. (3) The metal oxides so formed must then be *reduced*. Reduction may be accomplished by the use of:

a) *Carbon*. Coke is the most common reducing agent. When coke is used, a *flux* must always be added to combine with the foreign materials (the gangue) in the ore to form a crude form of glass (the slag), which floats on top of the molten metal and, incidentally, protects it against oxidation. It will be pointed out in the next Section that lime and silica are the principal components of glass. If the gangue is siliceous, limestone is added as a flux, and vice versa.

b) *Hydrogen*. Hydrogen is used in the reduction of tungsten oxide.

c) *More active metals*. Aluminum also serves as a powerful reducing agent in cases where carbon will not serve. The thermite process may be used to obtain chromium. It consists of igniting a mixture of chromium oxide and aluminum powder:

$$\underset{\text{chromium oxide}}{Cr_2O_3} + \underset{\text{aluminum}}{2\,Al} \longrightarrow \underset{\text{aluminum oxide}}{Al_2O_3} + \underset{\text{chromium}}{2\,Cr}$$

Welding of iron is sometimes accomplished by the thermit process. A mixture of iron oxide and aluminum is placed in and around the joint to be welded, and the mixture is ignited. The reaction produces superheated molten iron, which welds the two pieces of iron.

d) *The electric current*. Very active metals may be prepared by using the electric current as the source of the electrons which must be added to metals in the reduction process.

Sodium, potassium, magnesium, and aluminum are among the metals that are separated by the electrolysis of their molten compounds.

(4) After reduction, the crude metal must usually be freed from small quantities of other metals by *refining* processes. This involves a remelting with a proper flux, distillation, or electrolysis.

The light metals are less easily reduced than the heavier ones. As a general rule, they are separated from their compounds, after concentration, by electrolytic processes.

Advances in Steel Manufacture Have Enabled Man to Produce Improved Machines.

The iron obtained from the blast furnace is called *pig iron*. It contains several per cent each of carbon and silicon, besides other

impurities. Pig iron may be cast into molded shapes to produce cast iron. There are two types of cast iron, depending upon the rate of cooling. Gray cast iron, formed by slow cooling, is cheap, readily machined, but only half as strong as steel. White cast iron, formed by quick chilling, is strong, hard, but too brittle for some purposes. A softer *malleable iron* is produced by properly heat-treating a special grade of white cast iron. The mechanical treatment of the high-melting product is an important part of its production. Wrought iron, used for pipes, bolts, chains, and grate bars, is produced from cast iron by reducing the amount of impurities and removing excess slag, then rolling and hammering the resulting product.

Cast iron, malleable iron, and wrought iron cannot be annealed, hardened, or tempered as is steel; for many purposes, only steel can be used. Steel is obtained from pig iron by removing carbon and some of the impurities and then adding definite proportions of carbon, manganese, or other elements to obtain the properties desired. There are four chief types of steel:

(1) *Crucible steel* is made by melting wrought iron with charcoal in a graphite or fire-clay crucible. Carbon is thus added to the iron to produce a uniform, hard, brittle product especially adapted for use in such articles as watch springs, razor and knife blades, and other tools in which the selling price per pound of steel is high.

(2) *Bessemer steel* is obtained from molten pig iron by oxidizing the impurities with a blast of air and then adding the desired amount of carbon and manganese. It may be produced very cheaply. The invention of the Bessemer process was perfected just before the American Civil War and has been largely responsible for the tremendous expansion of railroads since that time.

(3) *Open-hearth steel* is superior to Bessemer steel in that impurities are more completely removed by oxidation in a large open hearth heated with producer gas or natural gas. It yields a more uniform product than does the Bessemer process, and today about 80 per cent of the steel is produced by the open-hearth process. It is used for rails, bridge girders, armor plate, and other products requiring a strong but cheap material in large quantity.

(4) *Electric steel* is obtained by use of the electric furnace, which permits the iron to be kept in a fluid condition in a controlled atmosphere while other substances are added as desired. The best alloy steels are made in this way. Such steels are used when a very tough, dependable product is needed, regardless of cost, as in the manufacture of certain parts of modern automobiles and machinery.

Literally thousands of different mixtures of metals (*i.e.*, alloys)

have been investigated. Corrosion-resistant steels are now produced by adding silicon to produce such products as "duriron," while the addition of chromium and nickel produce "stainless steel." Tungsten, titanium, nickel, vanadium, cobalt, and molybdenum are added to produce other desired properties, and a variation of 0.1 per cent in some of these metals will produce a marked change in properties. A steel containing 11 to 14 per cent manganese is too hard to be machined and is therefore used in constructing burglar-proof safes and armor plate. The addition of a little zirconium (0.3 per cent) to nickel steel makes it very resistant to perforation by bullets. The addition of tungsten and other elements produces high-speed cutting-steels that do not lose their cutting-power even at white heat. These new cutting-steels revolutionized shop practice by enabling cutting-tools to plow through steel ten times as fast as formerly. "Invar" is a nickel steel which contracts or expands very little with changes of temperature and is therefore used in watches and measuring instruments.

Space will not permit an account of many other valuable alloys. It is important to note that the properties of steels depend quite as much on heat treatment as on chemical composition. When red-hot steel is slowly cooled, it is said to be *annealed*. If it is cooled very suddenly, as by quenching in water or oil, it is *hardened*. Hardened steel may be tempered by reheating to a temperature much below redness. These and other methods of treating steels produce in the finished product different types and sizes of crystals that play a very important part in determining its properties. Modern metallographic methods, in which the crystalline structure of the steel is studied, enable the steel industry to carry out the various methods of treatment under scientific control. The use of X rays has also been of great value in detecting and locating flaws in metals, as well as in a study of the structure of steels.

The Prevention of Corrosion Is Being Accomplished in Many Ways.

The usefulness of iron and steel is limited by their tendency to rust. In spite of all the efforts made to combat corrosion, the losses due to this one item amount to millions of dollars a year. Corrosion is essentially a process in which metals form compounds (*i.e.*, lose electrons). When two metals are in contact with an electrolyte, corrosion will take place, inasmuch as one metal will always have a greater tendency to lose electrons than the other.

Corrosion will also take place when there is some substance present, other than another metal, which is capable of accepting electrons.

Acid solutions contain hydronium ions, $(H_3O)^+$, which will accept

electrons and liberate hydrogen gas. Oxygen gas of the air in the presence of water will also accept electrons to produce hydroxyl ions, $(OH)^-$. Iron and steel will therefore corrode in very weakly acid solutions or even in the presence of water containing an abundance of dissolved oxygen.

Cathodic protection is successfully used for buried pipe lines, cables, etc. It consists in placing "anodes" in the soil and maintaining an electromotive force of a few tenths of a volt between these "anodes" and the metal to be protected, which, as long as it is cathodic, resists corrosion because it cannot lose electrons as long as it is positively charged. The anodes are slowly sacrificed by electrolysis, but they can be replaced at low cost.

Different points on the surface of a metal may vary in their tendency to lose electrons, due to differences in the composition of the metal at different points on the surface, differences in hardness, strains due to poor annealing and other causes, differences in crystal orientation within the metal, differences in exposure or radiation, differences in the composition of the dust particles at different points on the surface, differences in dust concentration, differences in moisture, and many other factors.

Although corrosion is a very complex problem, great progress is being made in methods of combating it. In nearly every case corrosion is prevented by covering the metal with a surface film which will prevent contact with oxygen or water. Iron, properly cleaned and dried, is painted, and as long as the paint film is maintained intact and impervious to moisture, no corrosion will take place. The first coat of paint usually contains red lead as the pigment, although zinc chromate is replacing it, particularly for under-water work. Exposure to sunlight, water, and air quickly oxidizes the paint vehicle and therefore allows the pigment to dust off. Iron may also be protected for some uses by giving it an initial protective coating of iron oxide. This is done in a number of different ways. Black iron oxide is produced by dipping the articles in melted potassium nitrate, KNO_3. This produces the familiar blue coat on such articles as watch hands. A film of oil or grease prevents rust. Likewise, the porcelain-like enamel of stoves and kitchenware prevents rust as long as no portions are cracked or chipped off. Once broken, however, the rust spreads under the enamel, and it begins to scale off. In many cases rusting is prevented by coating the iron with a metal which is not so easily corroded. Nickel was once used widely for this purpose, but it is now supplanted by the even less corrodible and more beautiful chromium. Electroplating with chromium is an achievement of the last

twenty years. Copper is sometimes used to coat iron, but copper is so readily tarnished itself that it is not always a desirable coating for iron, although it will prevent rust as long as it covers the whole surface.

Metallic coats may be applied by electrolysis; by electrochemical displacement, as in the case of copper, zinc, tin, nickel, chromium, and cadmium; by dipping the iron into the molten metal as in the case of zinc, tin, and aluminum; by spraying with the recently invented metallic-spray guns, which melt the metal and spray it on a surface in one operation; by cladding, *i.e.*, heating thin sheets of such metals as copper, nickel, or aluminum into the surface; by using the finely divided metal as a paint pigment; and by various other methods. As mentioned above, tin and zinc may be applied to iron by dipping in the molten metal. Tin is the favorite material for cans and pans. It affords excellent protection as long as the surface is unbroken because it reacts with the oxygen of the air to form on its surface a thin film of tin oxide, which resists further action. Tin is below iron in the electrochemical series and therefore accepts electrons from the iron, once the surface is scratched, so that the iron then rusts even more rapidly than it would in the absence of the tin. Zinc, on the other hand, is above iron in the electrochemical series, and all of the zinc will go into solution before the iron is attacked. Galvanized iron is therefore preferred to tin for many purposes, but it cannot be used in contact with foods because it may dissolve to produce toxic zinc compounds.

Cadmium, a metal similar to zinc, is now being used as a metallic coating, especially of hardware articles.

Zinc may be applied to iron by the Sherardizing process, in which the articles are heated with zinc dust in a tight drum to 800° F., thus forming alloys at the surface.

Aluminum powder in fine flakelike form is now widely used as a pigment in paints for the protection of bridges, oil tanks, and many other metal structures. Aluminum, like tin, does not easily corrode, because it forms a protecting layer of aluminum oxide on its surface; if it were not for this fact, aluminum would corrode more readily than iron because it is above iron in the electrochemical series and, therefore, has a greater tendency to give up electrons.

In 1907 *Thomas Coslett*, an English chemist, invented the process which now is known as the "Parkerizing Process." It consists of producing a coating of basic iron phosphate by dipping the iron into a hot, dilute solution of iron phosphate. This process gives a pleasing dull-black finish that serves as an excellent base for paint or enamel.

Iron is sometimes coated with asphalt, rubber, or glass to prevent corrosion.

The newer types of corrosion-resistant alloys are unfortunately relatively expensive, but as cheaper alloy steels and steel substitutes become available, corrosion problems in many cases will be solved by their use.

The Use of Aluminum Is Expanding.

In 1884 *Frank M. Jewett*, of Oberlin College, standing before his class, predicted: "The man who makes aluminum available for commercial use will be a benefactor to the world. He will also be able to lay up for himself a great fortune." *Charles Martin Hall*, one of the members of the class, took up the challenge. In less than a year after his graduation he invented a method of preparing aluminum by the electrolysis of aluminum oxide which was dissolved in molten cryolite.

On February 23, 1886, he rushed from his father's woodshed laboratory to show his sisters the first buttons of aluminum which he had made, and then with boyish enthusiasm he hurried to the college and shouted, "Professor, I've got it!"

Charles Martin Hall left a great fortune to his Alma Mater when he died, and his process, which is still used today, has been of great benefit to the world. By it, aluminum is now produced from bauxite (aluminum oxide) ore and sold at less than twenty cents a pound, whereas it cost eight dollars a pound when Hall began his experiments,

In 1940 the Tennessee Valley Authority announced that *John H. Walthall* had discovered a method for separating aluminum from clay. This process is said to involve the preparation of aluminum oxide from clay by its action with sulfurous acid. The oxide is then reduced by the Hall process.

Aluminum is finding extensive applications in transportation on land, air, and water; as a material for electric conductors, cooking utensils, machinery, and electrical appliances; in the metallurgy of iron and steel; in building construction; and as a material for containers and other equipment in the chemical, food, and beverage industries. Not only is pure aluminum used for some of these applications, but aluminum is given strength and other desirable properties by alloying it with magnesium, silicon, copper, and other metals. Other desirable properties, such as increased strength, may be produced in the case of certain alloys by heat treatment. As an example of the numerous applications of aluminum, there may be cited the 430,000 miles of aluminum, steel-reinforced, high-tension, electrical transmission cable which have been installed in the United States

alone. Aluminum and its alloys make possible modern transportation by the all-metal airplane, the streamlined train, and trucks, where dead weight must be eliminated. It is even finding application in the construction of bridges, booms, and other structures where lightness is at a premium.

Aluminum is now meeting with some competition from other light metals. Magnesium, which is lighter than aluminum, is now produced at prices which enable it to compete with aluminum for some purposes. Magnesium metal is used not only in making light, strong alloys but also in producing flashlights and flares; for example, 320,000-candle-power flares lasting ten minutes enable airmen to aim bombs or take pictures at night.

Beryllium is the other contender among the light metals. It is a very light metal; but, unfortunately, large deposits are not available, and it is expensive to extract from its ores. However, it is a valuable alloying element in small amounts in other metals; a good example is beryllium bronze.

Other Metals Are Finding Fields of Usefulness.

Tungsten is a metal with many valuable properties. It is very hard, is insoluble in acids, and has a very high melting-point. Because of its high melting-point and low electrical resistance, it is used as an electric-light filament.

Platinum is a useful metal, most of which is wasted in making jewelry, so that its price is very high. Many substitutes for platinum are now available. The other members of the platinum family, palladium, rhodium, osmium, and iridium, are now used for many purposes where a metal that will resist the action of other substances is needed.

Nickel (the United States nickel coin is 75 per cent copper and 25 per cent nickel) is especially valuable in the preparation of alloys. Nickel imparts toughness, heat resistance, and noncorrosive qualities to other metals. Stainless steels have a high nickel content, while monel metal is an alloy of nickel and copper. German silver is an alloy of nickel, copper, and zinc.

Copper also plays a versatile role in alloys, but its most important applications are in the electrical industry, because it is the most economical electrical conductor.

Bismuth is used to prepare low-melting-point alloys. Metallic barium has recently been produced as a commercial article. Pure molybdenum is now used in the form of sheet, rod, and wire in the electrical and radio industries. Cerium, which, when alloyed with other

metals, produces pyrophoric alloys for pocket lighters and toys, is a powerful reducing agent and can be produced at a relatively low cost from the available abundant raw materials. Cesium and rubidium are used in photo-electric cells. Present research indicates that cesium will be used to produce lamps of far greater efficiency than any known today.

Metallic tantalum serves as a cheap substitute for platinum in spinnerets for rayon manufacture. Columbium is a beautiful metal with a promising future as an addition to certain alloy steels. Though many other metals have important special uses that are of benefit to humanity, space will not permit a discussion of them.

Not half of the metals have come into common use; there is still plenty of room for the expansion of the science of metallurgy. Who will be the first to discover practical uses for germanium, terbium, indium, thallium, neodymium, lanthanum, samarium, or scandium?

An automobile resembling a 1943 model would have weighed three times as much if it had been manufactured out of the lightest materials of equal strength known forty years ago.

Some of the Newer Methods of Handling Metals Vastly Extend Their Usefulness.

Fabrics, glass, or china may be thinly coated with gold at low cost, so that gold cloth or gold dinner services are within the range of almost any family.

Metals may be drawn to fibers of a fineness smaller than any other fiber. Platinum fibers one ten-thousandth of an inch in diameter are replacing spider-web filaments as crosshairs of surveying telescope sights. Textiles may be woven from metallic fibers, and cotton and other fibers may be metalized by coating them with metals.

Stainless steel and chromium may be obtained in highly polished, extremely thin sheets that make possible metallic finishes for building purposes at very low cost.

STUDY QUESTIONS

1. Which of the metals were known in ancient times? Why were these metals, rather than others, known then?
2. Discuss the operations of metallurgy.
3. What is steel? Discuss the different kinds of steel and the processes used in their manufacture.
4. Discuss corrosion as to (*a*) what it is, (*b*) how it is caused, and (*c*) methods of prevention.
5. Write all you can on the subject of aluminum.

6. List ten metals and mention at least one important use of each.
7. What are the reducing agents most commonly used in metallurgical operations?
8. Aluminum is a more abundant element than iron. How, then, do you account for the fact that aluminum is so much more costly than iron?
9. What are the most useful properties of tungsten?
10. Name a few metals added to steel to give such desirable properties as hardness, resistance to corrosion, etc.
11. Under what conditions will iron and steel corrode most readily?
12. Why does aluminum not corrode readily?

UNIT IX

SECTION 3

COMBUSTION FURNISHES THE ENERGY NECESSARY TO TRANSFORM MANY MINERALS INTO USEFUL MATERIALS

Photosynthesis, to be studied in the next Unit, stores the radiant energy of the sunlight in the forms of wood, coal, petroleum, and natural gas. The process by which this stored energy is released, in which carbon compounds react with oxygen to produce carbon dioxide, is called *combustion*. Combustion is not limited to the oxidation of carbon compounds, however, for *any oxidation reaction which produces heat and light is called burning, or combustion.*

The Discovery of Oxygen Revealed the True Nature of Combustion.

In 1771 *Carl Wilhelm Scheele* (1742–1786) first prepared oxygen by heating certain substances. Three years later *Joseph Priestley* in England, ignorant of Scheele's discovery, prepared oxygen by heating mercuric oxide by focusing the sun's rays on it by means of a "burning glass." Although Priestley discovered the clue to the true nature of combustion, he refused to give up the then current phlogiston theory, and it remained for the great French chemist, *Antoine Laurent Lavoisier* (1743–1794), when he learned of Priestley's experiments, to realize that combustion is simply the reaction of materials with the oxygen of the air.

Oxygen Is the Most Abundant and Universally Active Element.

Fully half of the earth's crust is oxygen. It occurs uncombined in the air to the extent of about one fifth of the total volume, as pointed out in an earlier section.

The chief chemical characteristic of oxygen is its great readiness to combine with nearly all of the other elements, including both metals and nonmetals.

Not All Oxidation Reactions Take Place Rapidly Enough to Produce Combustion.

Most of the reactions which yield the same products as combustion reactions may take place so slowly that no light is produced and the

heat is dispersed nearly as fast as it is produced. Regardless of the rate of the reaction, the same amount of heat is evolved for the same amounts of reactants.

A log of wood will gradually decay as it lies on the ground in the forest, and it is eventually consumed, giving the same products and the same amount of heat just as truly as if it had been burned. All forms of decay are oxidation reactions which are caused by living microorganisms.

Combustion Sometimes Starts Spontaneously.

Sometimes the heat produced by decay accumulates until a temperature is reached at which combustion takes place; *this temperature is called the kindling temperature.* For example, an oily rag containing some oil such as linseed oil which is easily oxidized may start a fire. Linseed oil is used in paints because it will slowly combine with oxygen to form a tough, resistant coating. Such paints dry best when plenty of oxygen is available. If an oily rag is placed in a closet or some other place where the heat produced by the oxidation of the oil will not diffuse away as rapidly as it is produced, the kindling temperature may be reached and a fire started; such a process is called *spontaneous combustion.* Many fires are started by the spontaneous combustion of damp hay, paper, coal, and other organic materials.

An important factor in spontaneous combustion is that *the speed of a chemical reaction is roughly doubled or trebled for each ten-degree rise in the centigrade temperature.* Thus, as the temperature rises, heat is given off more and more rapidly until the slow oxidation becomes rapid combustion.

Some substances are so active with oxygen that spontaneous combustion takes place in even the most exposed places; thus a lump of white phosphorus left on the table will start burning spontaneously. Certain other substances having a higher kindling temperature will ignite spontaneously only on unusually hot days. A hot piece of iron placed in the vapor of carbon disulfide will cause it to ignite. When grease is spilled on a hot stove lid, it ignites because its kindling temperature has been reached. The purpose of a match used in lighting a fire is to raise the temperature of a portion of a combustible material above the kindling temperature.

Incendiary leaflets, dropped from airplanes during World War II, consisted of sheets of wet guncotton (nitrocellulose) containing finely divided phosphorus between them. After the guncotton dried, the phosphorus reacted with the oxygen of the air and ignited the guncotton, which burned with a hot flame.

Not All Substances Are Combustible.

Some substances such as carbon dioxide, CO_2, and silicon dioxide, SiO_2, will not combine with oxygen because the carbon and silicon in these compounds have already combined with all the oxygen that they can under the given conditions. Asbestos and fire clay are likewise incombustible and melt only at high temperatures. Such substances are called *refractories.*

Flames Are Produced by the Combustion of Gases.

Has it ever occurred to you as you watched the flames play over a burning log that the flames are merely the result of the combustion of gases driven from the log by the heat of the fire? A candle flame is produced by the burning of the vaporized wax after it has been melted and drawn up the wick. It is quite possible to heat wood or coal in the absence of air to drive off combustible gases. Artificial, or coal, gas is the chief fuel, especially for cooking purposes, in many cities.

Explosions Are Very Rapid Combustions.

Combustible gases or very finely divided dusts of combustible substances such as coal, cotton, flour, etc., when mixed with the proper amounts of air or oxygen, will explode violently if ignited. In such cases the activation of a few molecules is quickly propagated throughout all the gas present by the increasing temperature due to combustion, the whole mass of material being oxidized almost instantaneously with the evolution of large volumes of gases.

An Explosion Is the Result of Any Physical or Chemical Change Which Expands Gases Rapidly Enough to Set Up Sound (Detonation) Waves.

Such explosives as dynamite owe their explosive force to the large volume of gases suddenly set free, while other explosives such as a mixture of aluminum powder and liquid oxygen owe their explosive force to the sudden expansion of the surrounding air as the result of the rise in temperature due to the large amount of heat evolved almost instantaneously in the reaction which takes place.

Carbon Is the Most Important Fuel.

Carbon in the form of charcoal, coke, or coal is still our chief fuel. It may be burned directly, or it may be used to produce various fuel gases.

Carbon Monoxide Is a Dangerous Poison.

Carbon monoxide, CO, is produced when carbon and other fuels are burned in a limited supply of air. Inasmuch as it represents only a partial oxidation of carbon, it is readily oxidized to carbon dioxide and thus serves as a fuel gas.

Carbon monoxide combines with the red blood corpuscles, thus rendering the blood incapable of serving as a carrier of oxygen. Air containing as little as 1.5 parts of carbon monoxide to 1000 parts of air may be fatal if breathed for some time.

Carbon monoxide is odorless and thus fails to warn of its presence. It is likely to be produced in any stove, furnace, or combustion engine. A small automobile may produce enough carbon monoxide in a closed garage within three minutes to kill a man. Sometimes carbon monoxide leaks from defective exhausts into closed cars and is thus responsible for an unknown number of accidents. Protection against carbon monoxide poisoning requires that all exhaust gases be carried away through adequate flues, chimneys, and exhausts. Flues and chimneys should be checked occasionally to make sure that they are not stopped up with soot.

Fire-making Is No Longer the Difficult Problem That It Once Was.

One of the earliest matches was made in 1805 by *Chancel*, of Paris, who dipped sticks of wood in sulfur and tipped them with a mixture of potassium chlorate, sugar, and gum. This match was ignited by dipping the tip into a "fire bottle" containing asbestos saturated with concentrated sulfuric acid.

About 1827 *John Walker*, an English apothecary, invented a match with a tip composed of potassium chlorate and antimony sulfide, which was ignited by drawing it between folds of paper coated with powdered glass. This match, known as the lucifer, or friction, light, was the first friction match.

In 1852 the first Swedish safety match using red phosphorus was manufactured. Red phosphorus is an allotropic form (*a physically distinct form of an element with different energy content*) of phosphorus which is much less active than white phosphorus and is nonpoisonous. The red phosphorus is mixed with antimony sulfide and powdered glass and placed on the match box. The match tip consists of a mixture of antimony sulfide and some oxidizing agent such as potassium chlorate, $KClO_3$, red lead oxide, Pb_3O_4, or potassium dichromate, $K_2Cr_2O_7$. These matches can be ignited only by striking them on the prepared surface on the match box.

Modern matches are soaked in a solution of alum, sodium phosphate,

ammonium phosphate, or some other salt which partially fireproofs them so that the wood ceases to glow as soon as the flame is extinquished.

Modern "strike anywhere" matches are tipped with a mixture of phosphorus sulfide, P_4S_3, and some oxidizing material such as potassium chlorate, $KClO_3$, powdered glass or some other material to increase the friction, and glue to bind the ingredients to the match. The wood is usually impregnated with paraffin to render it more readily inflammable.

The Principle of the Match Is Employed in Fireworks.

The essential principle employed in the manufacture of matches and fireworks is to use a mixture of a readily oxidizable material and a powerful oxidizing agent, the components of which will react with each other as soon as the kindling temperature is reached. The reaction is usually a specialized kind of combustion in which the oxygen is furnished by a compound which readily gives it up on heating. The old black gunpowder was a mixture of powdered charcoal (14 per cent), sulfur (11 per cent), and potassium nitrate (75 per cent). In this case potassium nitrate, KNO_3, furnishes the oxygen for the combustion of the carbon and sulfur to form a mixture of gases. Gunpowder is still used for mining operations and in pyrotechnic displays, but it has been replaced for use in guns by more powerful smokeless powders.

Firecrackers are made by wrapping gunpowder in paper. Flash crackers use a mixture of magnesium and some oxidizing agent such as potassium chlorate instead of gunpowder. Colored lights are produced by mixing various substances such as strontium chlorate with mixtures similar to gunpowder. Strontium salts produce red fire; barium, green; sodium, yellow; magnesium and aluminum, white; and Paris green blue.

Magnesium is used in warfare for incendiaries and flares because, as it burns, its temperature is raised to the boiling-point, producing magnesium vapor which burns in air with a very hot flame of great brilliance. Magnesium is used in incendiary bombs partly because of its low density. It is ignited with thermite. Once ignited, burning magnesium, instead of being extinguished by water, reacts with water to produce hydrogen which burns with even greater intensity than the magnesium itself. Magnesium bombs are extinguished by covering them with sand or asbestos blankets to shut off the oxygen supply.

Thermite is a mixture of iron oxide and aluminum, which, when ignited by a primer of aluminum or magnesium powder mixed with some oxidizing agent such as barium peroxide, BaO_2, burns furiously.

Huge thermite incendiary bombs were used in World War II very effectively.

Fire Extinguishers Employ Completely Oxidized Carbon Compounds.

Water extinguishes fires by lowering the temperature of the burning object below its kindling point and by shutting off the oxygen supply. The steam formed may be a factor also. The various types of more efficient fire extinguishers are based on the principle of smothering the fire by preventing an access of air (oxygen), just as a blanket wrapped around a person whose clothes are on fire will smother the flame. An excellent example of this smothering action is the use of foam to extinguish fires in liquid fuels.

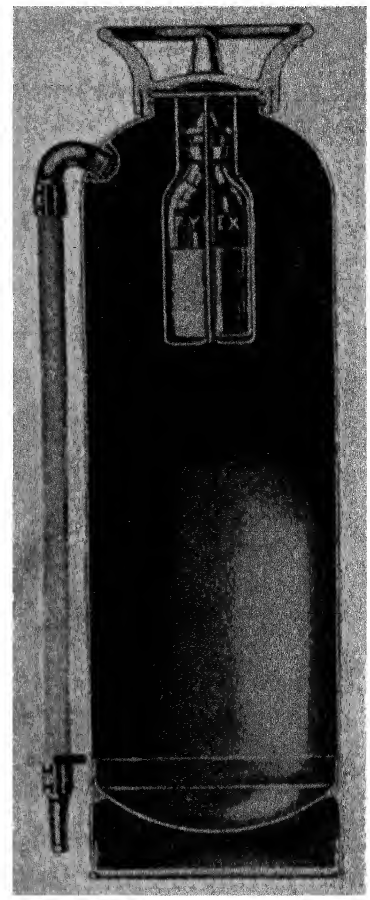


FIG. 283. Section of a soda-acid fire extinguisher. (Courtesy of the American-La France and Foamite Industries, Inc.)

The majority of fire extinguishers use carbon dioxide for one reason or another. One type of fire extinguisher, called the soda-acid type, consists of a fairly large cylinder containing a solution of sodium bicarbonate and a bottle of sulfuric acid. The acid pours into the baking soda solution when the cylinder is inverted, thus generating carbon dioxide. The carbon dioxide liberated in the above reaction produces a pressure that causes relatively large amounts of the carbon dioxide to dissolve in the solution and forces the resulting solution out through a nozzle. In this case, the water serves to extinguish the fire, but the carbon dioxide has little if any value except as an expellant. In the foam type of extinguisher, a licorice extract is added to the carbonate solution to produce a foam, and alum (aluminum sulfate, $Al_2(SO_4)_3$) replaces the sulfuric acid of the soda-acid type. The alum hydrolyzes to produce sulfuric acid in this case. The foam issues from the nozzle, each bubble being filled with carbon dioxide.

Some very efficient fire extinguishers use liquid carbon dioxide which produces carbon dioxide snow as it is sprayed on a fire and serves to smother (not cool) the fire by diluting the inflammable mixture of air and fuel. In another type of fire extinguisher finely divided particles of magnesium carbonate, $MgCO_3$, or sodium bicarbonate, $NaHCO_3$, are forced onto the fire with the pressure produced by liquid carbon dioxide or compressed nitrogen.

The vaporizing-liquid type of extinguisher contains carbon tetrachloride, which is forced onto the fire by a pump in the cylinder. Carbon tetrachloride is a compound in which the carbon has been completely oxidized by chlorine rather than by oxygen. Carbon tetrachloride forms a heavy vapor that smothers certain types of fires such as oil and gasoline fires quite efficiently if the vapors are confined over the surface of the fuel.

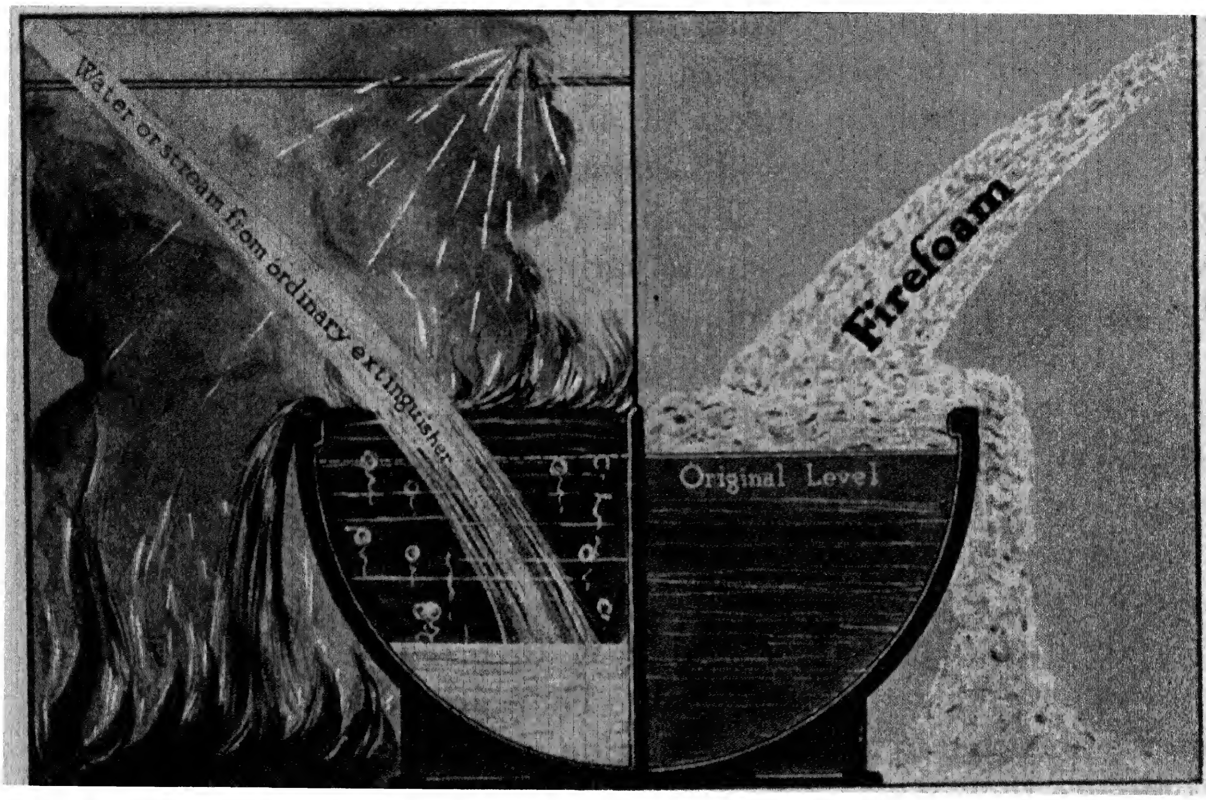


FIG. 284. Note how the foam floats on the liquid shutting off the oxygen and extinguishing the fire, and how the water goes to the bottom of the receptacle allowing the burning liquid to overflow and the fire to spread. (Courtesy of the American-La France and Foamite Industries, Inc.)

Combustion Furnishes the Heat to Transform Many Inorganic Materials into Useful Products.

1. Limestone Is Heated to Produce Lime. Any naturally occurring carbonate, such as calcium carbonate (limestone, chalk, or marble) or magnesium carbonate (magnesite), when heated to a high enough temperature in large furnaces, or kilns, will decompose to form carbon dioxide and the corresponding metallic oxides — lime, CaO, in the case of limestone.

Lime, CaO, called quicklime, will react with water to form hydrated lime, $Ca(OH)_2$. This process, called "slaking," evolves considerable heat. When lime is left exposed to the air, it combines with the carbon dioxide to form calcium carbonate, $CaCO_3$. This product is called "air-slaked" lime.

Because of its low cost, hydrated lime (calcium hydroxide, $Ca(OH)_2$)

is much used in industries whenever a mild alkali is desired. Hydrated lime is an important constituent of mortar, plaster, and stucco. Ordinary mortar consists of a mixture of hydrated lime, sand, and water; when exposed to the air, the water evaporates, and the mortar slowly sets as the calcium hydroxide reacts with the carbon dioxide of the air to form artificial limestone, $CaCO_3$, containing sand.

Interior plasters contain plaster of Paris as their principal constituent. Plaster of Paris is obtained from naturally occurring gypsum, $CaSO_4 \cdot 2\ H_2O$, by heating it to drive off a part of its water to form $CaSO_4 \cdot \frac{1}{2}\ H_2O$. When plaster sets, the reverse reaction slowly takes place. As plaster of Paris sets, it swells slightly and is therefore very useful for preparing casts of various kinds.

Stucco, *i.e.*, exterior plaster, usually contains both lime and cement.

2. Portland Cement May Be Made by Heating the Proper Mixtures of Certain Very Abundant Rocks. The invention of Portland cement revolutionized the building and construction industries by enabling man to produce artificial stone in any shape desired, thus saving immense amounts of labor that would otherwise have been expended in cutting stones.

Modern Portland cement is produced by intermingling raw materials rich in lime, CaO, with other materials rich in alumina, Al_2O_3, and silica, SiO_2. The lime is usually obtained from low-grade limestone, chalk, or shells. The alumina and silica are furnished by clay, shale, slate rock, volcanic ash, or other materials such as blast-furnace slag. These raw materials are analyzed and mixed in the proper proportions. The manufacturing process consists in grinding the material very finely, mixing it intimately, partially fusing it in a rotary kiln at a very high temperature, and then grinding it to an extremely fine powder in rotating tubes partially filled with steel rolls or balls.

When Portland cement is mixed with water or with a mixture of water, sand, and gravel to form concrete, it takes an initial set within a few hours and continues to harden slowly for months or years. This hardening process consists, in part at least, in the hydration, *i.e.*, chemical combination with water, of the anhydrous compounds produced during the burning of the cement, to produce synthetic silicate rocks. These synthetic rocks may be made stronger than natural rocks by the use of reinforcing steel. Concrete should be kept wet when setting in order to provide plenty of water for the hydrating process.

3. Ceramic Products Have Also Replaced Natural Stone and Provided Entirely New Building Materials. The manufacture of brick and other clay products such as pottery was among the first advances made by man in the realm of material transformations.

Portland cement is high in lime, whereas in glass silica predominates. Ceramic products, such as pottery, earthenware, and porcelain, occupy, generally, a position between these two extremes. The ceramic products are of three types:

(1) Unglazed, porous materials such as bricks, pottery, and terra cotta.
(2) Partially glazed, porous materials such as earthenware and sanitary ware.
(3) Nonporous materials such as stoneware, chinaware, and porcelain.

The type of product produced depends to a large extent on the very careful selection and analysis of raw materials, although the great improvements made in these products in recent years have been paid for only by very extensive research.

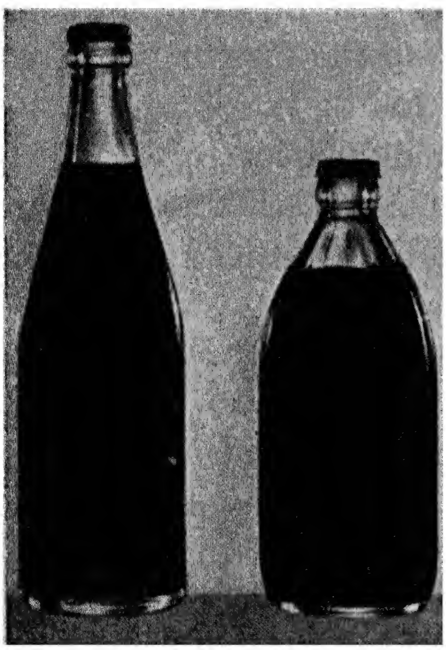


FIG. 285. Left, old juice bottle. Right, new juice bottle, equal in capacity but lighter in weight. Changes in the design of glass bottles to stronger bottles containing less glass accounted for an increased production capacity of 2,500,000 gross of glass containers in 1939. (Courtesy of *Industrial and Engineering Chemistry*, News Edition, published by the American Chemical Society.)

Glass Is One of the Most Important Industrial Products of Today.

Ordinary "soft glass" such as used in window panes and bottles is "lime-soda" glass; that is, it is a sodium calcium silicate, produced by melting together calcium carbonate, sodium carbonate, and quartz (sand, or SiO_2). When these materials are heated, carbon dioxide is evolved, and the resulting products consist of about 1 part sodium oxide, Na_2O, 1 part calcium oxide, CaO, and 6 to 8 parts silica, SiO_2. The Na_2O and CaO may be partially or entirely replaced by other oxides such as BaO, K_2O, ZnO, or PbO. Thus lead glass used in cut-glass ware contains PbO. The SiO_2 may also be replaced by B_2O_3, P_2O_5, and other oxides. Heat-resisting glasses, for example, are often borosilicate glasses, which are high in boron oxide, B_2O_3, content.

Highly stable borosilicate glasses were first developed in America some thirty years ago. Their resistance to mechanical shock and sudden temperature changes has brought them into wide use for cooking utensils, while their resistance to chemical reagents, along with

their other properties, has resulted in their almost universal adoption for chemical laboratory glassware.

Colored glass is obtained by adding small traces of the oxides of heavy metals; thus cobalt oxide imparts a blue color; selenium oxide, a ruby red; chromium trioxide, a green; manganese dioxide, a violet; and iron oxide, an amber color.

One of the latest developments in building is the use of glass blocks. These blocks can be improved as to their insulating and light-diffusing properties by sealing sheets of Fiberglas into them.

Melted glass can be passed through tiny holes or pulled out to produce threads that are less than one tenth of the diameter of a human hair. These fibers can be spun into moistureproof, verminproof, rot- and mildewproof, fireproof cloth. Because of their electrical insulating properties glass fabrics are used in the electrical industry for such applications as battery-plate separators. At present glass fabrics are too harsh for wearing apparel in direct contact with the skin and have limited utility in uses involving much wear or flexing. Glass wool is widely used in air conditioning as a filtering medium and an insulating material.

Mineral wool, a product similar to glass wool, is likewise widely used for heat and sound insulation. The raw materials for mineral wool are slags, formerly the waste products from the refining of metals, to which certain rock materials are sometimes added to impart the desired properties to the final product. The mineral wool is usually produced by melting the slag or slag-rock mixture and then blowing air or steam under high pressure into a small stream of the molten material.

STUDY QUESTIONS

1. Differentiate between quicklime and hydrated lime.
2. What is the composition of mortar, and what reaction takes place when it sets?
3. Why is it desirable to keep concrete wet while it is setting?
4. Discuss mineral wool as to (*a*) its preparation, and (*b*) its uses.
5. Discuss Portland cement as to (*a*) composition, (*b*) raw materials, and (*c*) method of manufacture.
6. Discuss glass as to (*a*) composition, (*b*) raw materials, (*c*) types of glass, and (*d*) modern uses.
7. Discuss the progress that man has made in duplicating the materials produced in nature.
8. Discuss plaster of Paris as to (*a*) its preparation, (*b*) its uses, and (*c*) what happens when it sets.
9. Discuss the nature of incendiary bombs.

10. What conclusions may be based on the following experimental data?
    Moistened iron filings rust when confined in a closed vessel with air, the volume of the air being decreased in the process. The air remaining does not support combustion or life.
11. What is combustion? Give two or three examples. What discovery led to an understanding of the true nature of combustion?
12. What is spontaneous combustion? Give some examples. How would you demonstrate it?
13. Combustion is the opposite of photosynthesis. Explain what is meant by this statement.
14. What is the nature of a flame?
15. Discuss carbon monoxide as to (*a*) conditions which produce it, (*b*) its properties, and (*c*) why it is dangerous.
16. Discuss the composition of safety matches.
17. Discuss the composition of "strike anywhere" matches.
18. Discuss the principle employed in fireworks.
19. Discuss fire extinguishers as to (*a*) the principle of each type, and (*b*) the conditions for which each type is best suited.
20. Give a general rule for the effect of an increase in temperature on the speed of a chemical reaction.
21. What is the nature of an explosion?
22. What materials are used in the foamite type of fire extinguisher?
23. Prepare a list of applications to which glass fabrics are best suited.

UNIT IX

SECTION 4

AIR AND WATER ARE TRANSFORMED INTO MANY USEFUL MATERIALS BY SYNTHESIS IN THE PRESENCE OF CATALYSTS

When man tries to prepare compounds found in nature, he often finds it necessary to utilize very high temperatures or pressures; but it is typical of nature that its reactions take place relatively rapidly at ordinary temperatures and pressures. The secret of chemical reactions in nature seems to lie in *catalysis*. *A catalyst* is a substance which needs to be present in only very small amounts either to activate molecules in such a way that reactions which would otherwise take place so slowly as to give no appreciable results take place quite rapidly or, less frequently, to produce a marked decrease in the rate of a chemical reaction. It is also characteristic of catalysis that the catalyst does not become a part of the products of the reaction.

The study of many processes taking place in nature led scientists to the conclusion that nearly every chemical change can be catalyzed. Some of the greatest developments of modern chemistry are the results of attempts to find the proper catalysts for desired reactions.

Synthesis is the building of more complex substances from simpler ones. The preparation of water from oxygen and hydrogen is an example of synthesis.

In many cases desired syntheses will take place only in the presence of the proper catalysts. The preparation of high explosives and fertilizers from air and water are typical examples of processes which involve the use of catalysts.

Catalysts Are Effective in Very Small Concentrations.

It is customary to prepare oxygen in the laboratory by heating potassium chlorate, $KClO_3$. The addition of a small amount of manganese dioxide, MnO_2, will cause this reaction to take place much more rapidly and at a lower temperature; in this case the manganese dioxide is the catalyst. The more of the catalyst that is present, the more rapid will be a given chemical reaction, but many reactions are noticeably accelerated by astonishingly small quantities of catalysts.

> The role which insignificant amounts of mineral matter play in reactions of this kind is indicated in the familiar trick of setting fire to a lump of sugar. The lump will not ignite on application of a lighted match, but if a speck of tobacco ash be added, the sugar will readily inflame.[1]

Moisture is a common catalyst; thus a dry mixture of carbon monoxide and oxygen will not explode even when in contact with a red-hot platinum wire, but if even a minute trace of moisture is present an explosion will take place at once.

Catalysis May Be Negative as Well as Positive.

As a general rule one is interested in increasing the rate of chemical reactions, but occasionally he desires to decrease the rate instead. The knock in an automobile engine is produced by the premature explosion of the gasoline in the cylinder. This knock can be remedied by adding an antiknock substance to the gasoline which decreases the rate of combustion of the gasoline; lead tetraethyl used in ethyl gasoline is a negative catalyst.

So effective is nicotine in retarding the oxidation of sodium sulfite that even a puff of tobacco smoke will produce a noticeable retardation.

The Nature of Catalysis Is Not Entirely Understood.

It is characteristic of many catalysts that they must be in an extremely finely divided condition to be active. Inasmuch as colloidal materials present a very great surface, one is not surprised to learn that many colloids serve as excellent catalysts. It is suspected that such processes are catalyzed by the adsorption of the reactants on the surface of the catalyst, which thus increases the effective concentration of the reactants. It has been learned, however, that catalysts are specific, *i.e.*, only certain reactions are catalyzed by a given substance. Inasmuch as the action of the catalyst depends so intimately upon its chemical nature, one cannot escape the conclusion that the catalyst actually enters into temporary combination with one of the reactants and thus activates it. If this combination should be permanent, the reaction would soon cease. There is good evidence in some cases of catalysis for the formation of such an intermediate compound, which then reacts with other molecules, thus liberating the original catalyst. The catalyst acts as a sort of chemical parson joining elements in the bonds of matrimony.

It is typical of surface catalysis that the catalyst is easily poisoned; thus mere traces of impurities, such as arsenic or phosphorus, will poison the nickel used to catalyze the hydrogenation of oils and thereby

[1] *News Edition*, American Chemical Society, Vol. 17, No. 23, Dec. 10, 1939, p. 736.

effectively stop the reactions. In this case it is probable that the surface of the catalyst is covered with a layer of the poisonous substance to a depth of one atom or molecule, which thus renders it unable to adsorb other substances.

The activity of catalysts may also be increased by the use of small amounts of foreign substances called *promoters.*

The intermediate-compound and adsorption theories mentioned above fail to explain some types of catalysis, and no satisfactory general definition has yet been found. We have a great deal more to learn about catalysis before we can hope to enter into successful competition with nature in the synthesis of many natural products.

Catalysis Plays an Important Part in Life Processes.

Microorganisms, sometimes called *nature's chemists*, bring about a host of chemical reactions by a secretion of catalysts called *enzymes.* Similar enzymes are produced in the higher plants and animals. It is the enzymes produced in plants that cause fruits to ripen. The digestion of foods by animals is greatly facilitated by the enzymes produced in the mouth, stomach, and intestines. Vitamins contained in foods act as physiological catalysts in animals, and it has been adequately demonstrated that many important reactions in the human body will not take place in their absence. The human body also secretes important catalysts, called *hormones*, which control the efficiency of the utilization of food, the rate and extent of growth, sexual development and activities, and many other functions. Some of man's greatest conquests of diseases have been accomplished by the analysis, synthesis, and controlled use of these organic catalysts. These physiological catalysts will be discussed in more detail in Unit X.

Nitrogen Fixation Is an Excellent Example of Synthesis Which Requires Catalysts.

The maintenance of the nitrogen supply of the soil is probably the most difficult problem involved in keeping up the fertility of the soil because nitrogen compounds are expensive and easily lost from the soil.

Nitrogen was formerly obtained from manures, and in some sections of the world, such as China, manures are still the chief source of nitrogen. Nitrogen may be added to the soil by legume crop rotation, but this process takes the land out of service, although it may even then pay; for example, 1533 pounds of seed cotton were obtained from an acre of ground after rotation with cowpeas, whereas only 837 pounds of cotton were obtained when grown year after year without a rotation of crops.

The nitrogen cycle in nature, shown in Fig. 286, summarizes the processes which contribute nitrogen to the soil.

There are huge deposits of nitrates suitable for fertilizers in Chile, which constituted the main source not only of fertilizer nitrogen but also of nitrogen for explosives up to the time of the World War of 1914–1918.

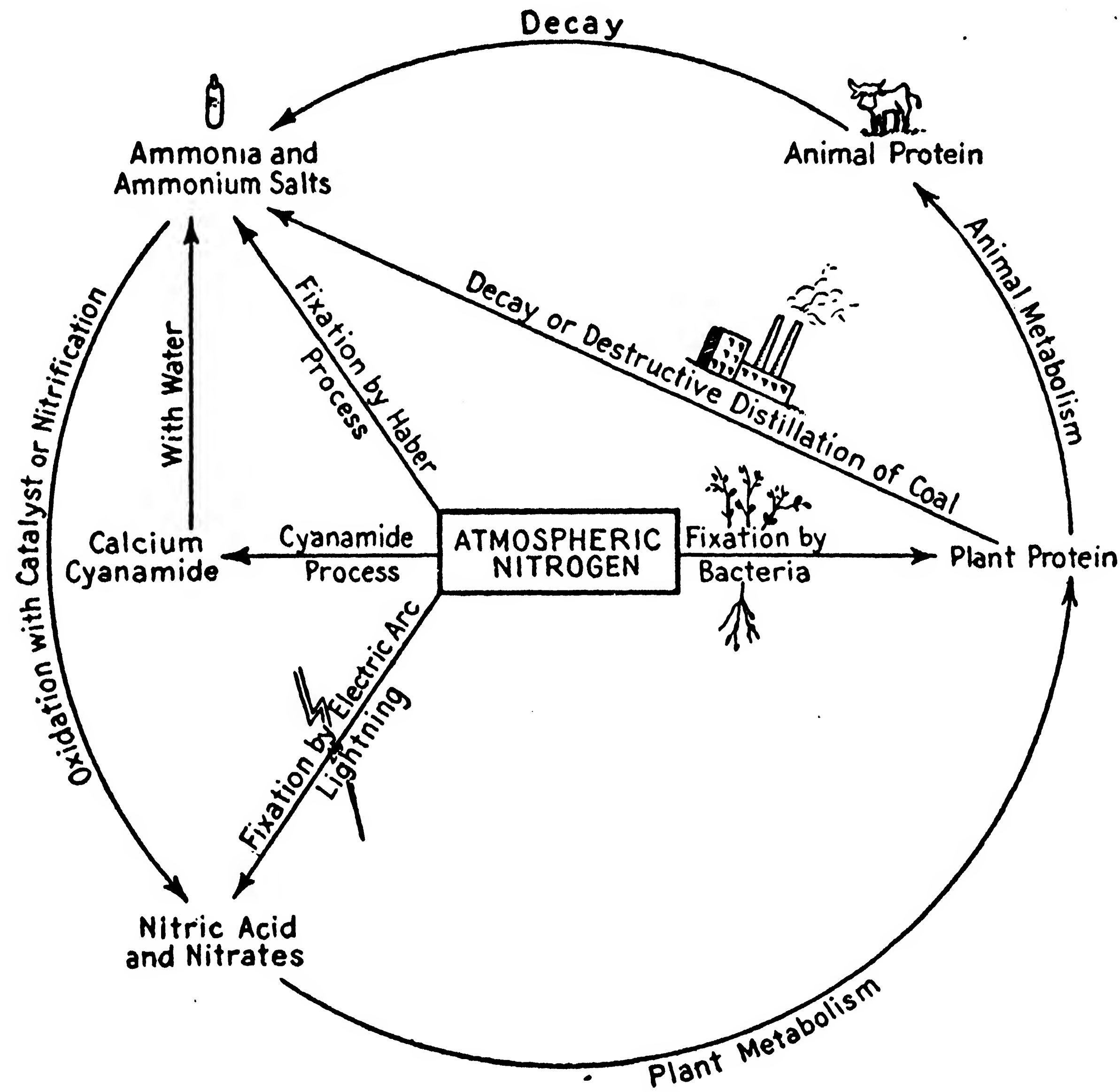


FIG. 286. The nitrogen cycle in nature.

High explosives are made with nitric acid, and nitric acid is made from nitrates. At the time of the first World War, Germany not only required additional nitrates for the production of foods, owing to the food blockade, but also for the production of explosives. The German High Command believed that this war would last only a few weeks and that her reserves, together with the ammonia obtained from the destructive distillation of coal, would meet her needs. The German armies had the luck to capture several ships laden with Chile nitrate at Antwerp, or their nitrate supply would have been exhausted long before the Haber process for the fixation of nitrogen was perfected

on a commercial scale. Four fifths of the air is nitrogen, but nitrogen is so inert that up to a few years before 1914 all efforts to combine it (this process is called *fixation*) with other elements on a large scale had met with failure. Here was a job which required the aid of a catalyst.

Fritz Haber's nitrogen-*fixation* method, which involved the heating of nitrogen and hydrogen under pressure in the presence of certain catalysts, was rapidly developed on a large scale in Germany when it became evident that the war was going to last longer than was expected. The hydrogen for this reaction may be prepared from water by electrolysis or by the action of steam on coke.

$$\underset{\text{coke}}{C} + \underset{\text{steam}}{2\,H_2O} \longrightarrow \underset{\text{carbon dioxide}}{CO_2} + \underset{\text{hydrogen}}{2\,H_2}$$

The first commercially successful nitrogen-fixation process was the arc process, in which nitrogen and oxygen combine when passed through an electric arc. This process is too expensive except where very cheap power is available, as in Norway.

The next process to be developed was the cyanamide process. Cyanamide plants were built throughout the world during the eight years preceding World War I. This process, it will be recalled, consists in heating calcium carbide with nitrogen to form calcium cyanamide.

After the war broke out, it became difficult to obtain information concerning the new Haber process; so the United States, forced to provide a nitrogen supply that would not have to be transported by steamer from Chile, selected the cyanamide process. It therefore constructed the largest cyanamide plant in the world at Muscle Shoals, Alabama, which, however, had never been in operation up to 1941 due to economic and political reasons.

During the war Germany constructed several cyanamide plants, the one at Merseburg alone having a production capacity corresponding to about two thirds of the previous total annual shipments from Chile.

In recent years several new processes for the fixation of nitrogen have been developed, and nitrogen-fixation plants have entered into competition with Chilean nitrates throughout the world. Today about 20 per cent of the world's nitrogen supply comes from Chile; 10 per cent comes from coal in the by-product coke ovens; and the rest comes from nitrogen-fixation processes.

Nitric Acid Is Now Prepared from Ammonia.

Ammonia, prepared by the Haber process, may be oxidized by passing a mixture of ammonia and air through chambers containing such catalysts as iron oxide or platinum gauze to form nitrogen dioxide,

NO_2, which reacts with water to produce nitric acid. Nearly all of the commercial nitric acid used in the United States today is prepared by this method.

Nitric acid is one of the most important of the *heavy chemicals.* It reacts with many organic compounds; for example, with glycerol it forms nitroglycerol, the principal active constituent of dynamite. Incidentally dynamite was discovered by Emanuel Nobel and his son Alfred when one of their cans of nitroglycerine leaked into the kieselguhr in which it was packed. This mixture was found to be more stable than nitroglycerine and came to be known as dynamite. Nitric acid reacts with cellulose to form nitrocellulose, whose many uses will be discussed in Section 7 of this Unit.

Nearly All Explosives Require Nitric Acid in Their Manufacture.

The black gunpowder of our forefathers was a mixture of charcoal, sulfur, and saltpeter, KNO_3. One of the earliest synthetic organic chemicals was mercury fulminate, $Hg(OCN)_2$ (mercury fulminate is prepared from mercury, alcohol, and nitric acid), which was introduced for percussion caps in 1819. In 1865 the Prussian army used smokeless powder made from nitrocellulose and nitroglycerine. Picric acid, $C_6H_2(OH)(NO_2)_3$, which is prepared by the action of phenol with nitric acid, came into use in the Boer and Russo-Japanese Wars for high-explosive shells; and T.N.T. was used on a large scale in the high-explosive shells of the World War of 1914–1918. T.N.T. (trinitrotoluene), $C_6H_2CH_3(NO_2)_3$, is prepared by the action of nitric acid on toluene, $C_6H_5CH_3$.

A new explosive, P.E.T.N. (pentaerythritol tetranitrate), came into use during World War II. It is made from formaldehyde, acetaldehyde, and nitric acid. The Italian explosive T_4 (cyclotrimethyltrinitramine) is made from formaldehyde, ammonia, and nitric acid. These two explosives are secondary explosives used for commercial blasting and as primers for high explosives.

Explosives Are Widely Used for Peacetime Pursuits in the United States.

To the average citizen, the word "explosives" is associated with battles and bursting shells, bomb outrages and burglars. To the quarry or mine operator, explosives represent a means to meet his pay-roll and pay dividends. To the engineer, they mean the second most important item in the construction of canals, the building of railroads, or the deepening of harbors, and in the production of the metal and mineral wealth, which has given the United States the dominant position it enjoys to-day.

The steel industry, considered the index of business in this country because next to farming it is our greatest single industry, is dependent upon explosives for the production of its finished product. In the extensive pit mines of the

Mesaba Range in northern Minnesota, explosives are used to break down the coal to be made into coke for the reduction of this iron ore. In the big quarries of the lower Michigan peninsula, explosives are used to blast out solid limestone, which is subsequently crushed and shipped to the furnaces where it is used for a flux with the coke and the ore for the manufacture of iron and steel. The ships and cars that convey these raw materials to the steel mill are moved by the energy in the coal blasted down by explosives. Not only are railroad trains and tracks, ships and engines, bridges and highways, buildings and automobiles, constructed from the metals or the stone produced by the aid of explosives, but also many familiar articles of everyday life are dependent at some stage on explosives for their economical production.[1]

The consumption of industrial explosives in the United States averages over 1,000,000 pounds a day.

Industrial Explosives Are Different from Military and Sporting Powders.

To most people, explosives are simply explosives, but in the minds of manufacturers and users they are classified in two general groups: first, military and sporting powders, which are mainly propellants with some disruptives like T.N.T. for shell bursting charges, mines and bombs; and, second, industrial explosives, which are all disruptives and are in turn divided into two classes; high explosives, including dynamite, and blasting powder or the familiar gun-powder.

These two groups are not interchangeable. Black powder is ruled out as a propellant in modern warfare, as the smoke produced on firing would disclose the location of the gun. Dynamite cannot be used as a propellant as its speed of detonation is so great it would shatter the gun; it cannot be used as a bursting charge in shells as the shock of shooting the shell from the gun would also set off the bursting charge and wreck the gun. Furthermore, bullets are usually flying around the seat of war and most dynamites would be set off if hit by a bullet.

Military explosives such as smokeless powder and T.N.T. are not open to these criticisms, but they cannot be used in mines and quarries as they are too weak for many types of rock, the fumes from their explosions are so strong with carbon monoxide that they would be unsafe in mines, and lastly, they are much more expensive than dynamite or black powder.

Not only is it impossible to use dynamite as a propellant or for shell-bursting charges, but dynamite manufacturing plants cannot be converted into smokeless powder plants in time of war. The only ingredients common to both are nitric and sulphuric acid. The dynamite manufacturing apparatus is entirely different, the processes and chemical composition totally unlike that of military explosives, and it takes a considerable period of time to train the personnel of both dynamite and smokeless powder plants in their specialties.[1]

Ammonia Has Several Important Uses.

Ammonia gas, NH_3, reacts with water to form the weak base, ammonium hydroxide, NH_4OH, which is so useful in house cleaning.

[1] *Explosives — Their Significance, Manufacture and Use*, E. I. du Pont de Nemours and Company, Inc.

Ammonia is frequently combined with phosphoric acid to produce important fertilizers that supply the phosphorus that the soil needs in addition to the nitrogen. Ammonia is also combined with sulfuric acid to form ammonium sulfate. Sulfuric acid in this case acts as an inexpensive carrier for the ammonia. Ammonia gas may be readily liquefied; in this form it is used extensively as a refrigerant in the manufacture of ice. Ammonia will react with nitric acid to produce ammonium nitrate, NH_4NO_3, used as a fertilizer and in making certain types of blasting agents.

The E. I. du Pont de Nemours Company has recently developed a practical process on a commercial scale for the production of sulfamic acid, HSO_3NH_2, which has many interesting uses based upon its unique properties. The ammonium salt of sulfamic acid is now used as a weed-killer and as a flameproofing agent. Keep your eye on this product; it is sure to go places.

The Air Contains Rare Elements Which Are More Inert Than Nitrogen.

The rare gases, helium, argon, neon, krypton, and xenon, are sometimes referred to as the old maids and bachelors of chemistry because their chemical inactivity is their chief property. So inactive are these elements that they do not combine to form diatomic molecules as most gases do; their molecules consist of one atom only.

Helium is next to the lightest gas known, having a lifting power 92 per cent of that of hydrogen, but unlike hydrogen in that it is not inflammable. The main source of helium is the natural-gas wells of western United States. It is used for airships and for the prevention and treatment of "bends," the disease of deep-sea divers and high-altitude aviators. A mixture of helium and oxygen is used in treating severe respiratory diseases such as acute asthma.

Neon and argon are used in gas-filled glow lamps. Argon is also used in filling electric-light bulbs, thus reducing the tendency of the hot filaments to vaporize.

Argon and neon are obtained along with nitrogen and oxygen in the fractional distillation of liquid air. Argon is present in air to the extent of 0.94 per cent by volume. One part in 65,000 parts of air is neon, while the other gases are present in such small proportions that they are too rare to have important uses.

STUDY QUESTIONS

1. Discuss catalysis as to (*a*) definition, (*b*) the types of catalysts, (*c*) examples of six different catalytic processes, and (*d*) the nature of catalysis.
2. Discuss physiological catalysts.

3. Give an example of negative catalysis.
4. What is meant by nitrogen fixation?
5. Why is nitrogen fixation of importance?
6. Discuss the various types of nitrogen fixation.
7. Show how nitrogen fixation was an important problem in the World War of 1914–1918.
8. Discuss the preparation and uses of nitric acid.
9. How was dynamite discovered?
10. From what raw materials are the important explosives prepared?
11. Discuss the preparation and uses of ammonia.
12. What is the outstanding property of the rare gases?
13. Where is helium obtained, and for what is it used?
14. Give the uses of argon and neon.
15. Starting with air and water, show how the important chemicals, ammonia and nitric acid, can be prepared.
16. It was found that such plants as cereals increase in growth in proportion to the concentration of nitrates in the soil, but that in the case of legumes, no such regularity was observed. Chemical analysis showed that these legumes contained more nitrogen than the soil could supply. In some cases, however, it was observed that legumes failed to thrive in soil containing nitrogen fertilizer. The hypothesis was suggested that bacteria in the root nodules of legumes were responsible for these differences between cereals and legumes. Work out detailed suggestions for experiments by which this hypothesis could be tested.
17. What are the uses of ammonium sulfamate?

UNIT IX

SECTION 5

CELLULOSE IS THE RAW MATERIAL FOR MANY "BETTER THINGS FOR BETTER LIVING"

Introduction.

The slogan of E. I. du Pont de Nemours and Company (the largest chemical company in the United States) is "Better Things for Better Living through Chemistry." In this Section there will be given a brief survey of some of the entirely new and "better things" which have been made from *cellulose* as a raw material. These new textiles, plastics, and other materials represent an improvement over age-old substances, making available hundreds of new products which are not only more beautiful and more durable, but also much cheaper than the natural products which they replace. In many cases these new products have found unique places for themselves which were never filled by natural products.

Perhaps even more important than the new products are the new jobs and higher standards of living which these synthetic materials make possible. Through the aid of chemistry we have been able to utilize waste products such as cotton linters to build an industry which provided employment for more than fifty thousand workers in the production of rayon alone in the United States in 1937.

The major portion of these developments have come since the World War of 1914–1918, and it is generally agreed that they represent but the merest sample of the achievements yet to be wrought by creative chemistry in the utilization of cellulose as a raw material.

Many New Products Are Now Made from Cellulose.

Cellulose, as we have previously learned, is a complex carbohydrate that makes up the framework of the woody and fibrous plants. Large amounts of cellulose, in the form of waste wood, straw, etc., are still burned annually to get rid of them; but it is predicted that it will not be long before man will be raising plants just for their cellulose. The industries using cellulose are divided into five main groups on the basis

of the extent to which the cellulose molecules are transformed in the manufacturing processes involved.

1. Cellulose in Slightly Altered Form. The use of cellulose in the form of lumber, textiles, and paper involves little more than certain physical processes such as carving, spinning, and weaving. As lumber becomes scarce, however, it is to be expected that many lumber substitutes will be devised which will use less wood and utilize waste products. Such developments as plywood come under this class. Sawdust, cork, sugar cane refuse, etc. are now used to prepare various types of composition boards.

Mercerized cotton is an example of a slightly altered form of cellulose. In 1844 *John Mercer* discovered that cotton fibers can be shortened and strengthened by passing them through a cold solution of lye. Later it was found that these fibers would change into smooth, silk-like tubes by stretching them during the drying process; thus mercerized cotton came into use.

Paper is made from wood, old papers, or rags. Much of the wood used for paper receives no chemical treatment at all but is merely ground to a fine pulp. Higher-grade pulp must be produced by a chemical process that will remove the lignin, *i.e.*, noncellulosic part of the wood. In the sulfite process, lignin is removed by heating wood chips in a closed vessel with calcium bisulfite. Lye and sodium sulfate are used for this purpose in other processes. The paper itself is composed chiefly of unaltered cellulose. The paper industry produced nearly two billion dollars' worth of products in 1939.

"Pervel" is a new fabric, unique in that it is produced by simply pressing cellulose fibers, such as is done in paper manufacture, and yet has the properties of cloth. It may be made to sell for but little more than it costs to launder cotton fabrics. "Pervel" aprons, curtains, table and bed linen, handkerchiefs, and many other products are now available for use on the "throw away" principle.

Parchment paper resembles mercerized cotton in that the surface is partially dissolved by sulfuric acid and is then allowed to dry. In parchment paper the fibers are bound together to the extent that the paper can be used as a dishrag without disintegration. Foods may be tied up in parchment paper and cooked, thus preventing loss of flavors, natural juices, and water-soluble substances, such as minerals, sugars, and vitamins.

Vulcanized fiber partially resembles parchment paper. It is produced by running paper through a solution of zinc chloride, which produces a gelatinous hydrated cellulose on the surface. The paper is then washed to remove zinc salts, wound in rolls, and pressed to pro-

duce a material harder than wood, but just as easily worked, nearly oilproof, and having good electrical insulating properties. Lumber may now be treated with the appropriate chemicals to prevent dry rot, infestation by termites, or shrinking and swelling in dry and damp weather, respectively.

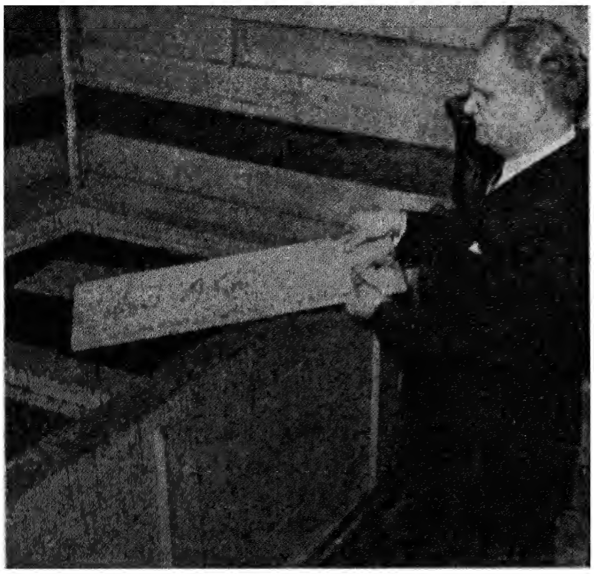


FIG. 287. Removing an oak board from the urea tank. (Courtesy of the U. S. Forest Products Laboratory.)

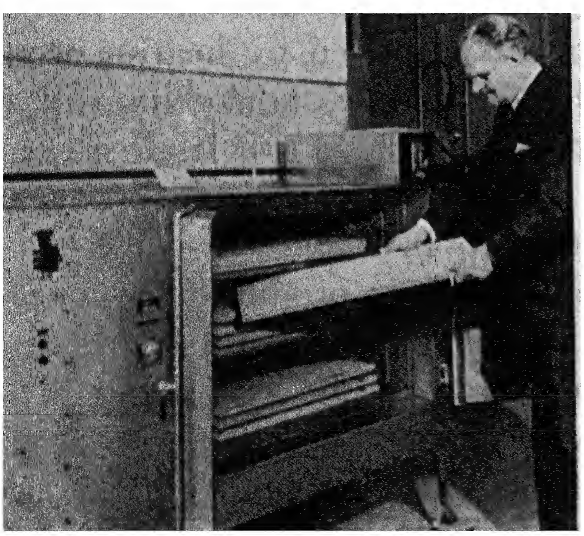


FIG. 288. Taking an oak board, previously soaked in urea, from the drying oven in plasticizing experiments. (Courtesy of the U. S. Forest Products Laboratory.)

Wood can be made plastic by soaking it in a concentrated solution of urea, drying, and then heating it to the boiling-point of water, at which temperature it can be readily shaped. When cooled, the wood retains its shape and resists further action of moisture. Sawdust and chips can be treated in this way and then pressed in molds when hot, forming products practically as strong as wood.

2. Cellulose Dissolved and Reprecipitated. Rayon, once called artificial silk, but really a new type of fiber entirely unrelated and in many ways superior to silk, is produced by dissolving cellulose in the proper solvent and then forcing the solution through small openings into a solution that precipitates the cellulose again in the form of fine threads. There are four different processes involved in the manufacture of rayon. Over 80 per cent of the rayon is now produced by the viscose process, in which cellulose is transformed into cellulose xanthate by the action of caustic soda and carbon disulfide. The cellulose xanthate is then dissolved in caustic soda solution.

The properties of rayon depend upon the nature of the manufacturing process. Rayon used in the cord fabric of tires has a high strength and durability at elevated temperatures. For dress fabrics a sheen higher than that of silk or the dullness of chalk may be achieved.

Filaments finer than silk make possible very soft fabrics. Rayon cut into small lengths and the new irregular thick and thin yarns have created entirely new textures in fabrics. Transparent velvet, dull satins, and textiles rivaling in beauty the finest cashmere are all made from rayon.

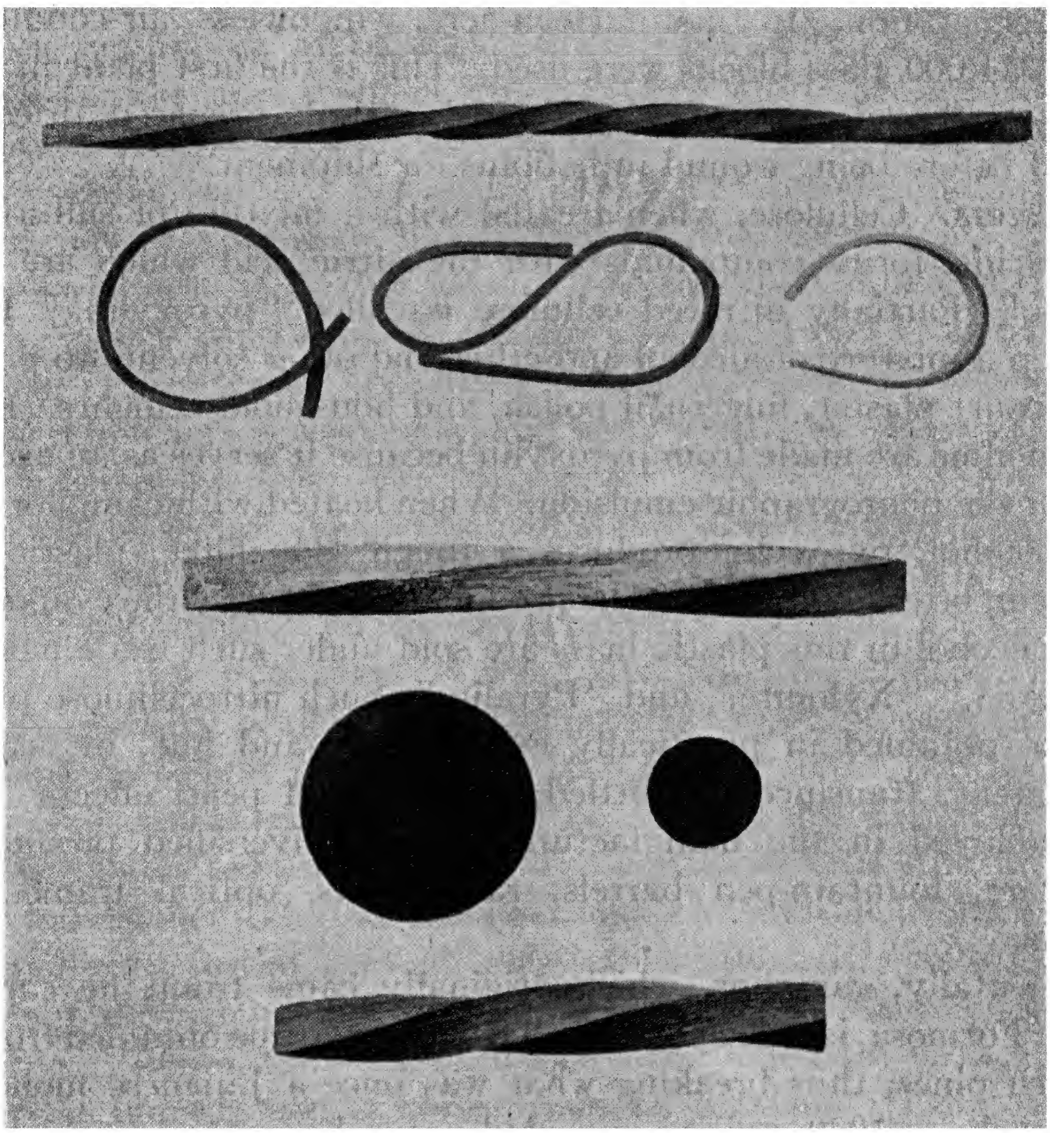


FIG. 289. Wood may be twisted or bent after urea treatment. (Courtesy of the U. S. Forest Products Laboratory.)

The cellulose in viscose, as the thick yellow cellulose solution is called, may also be regenerated in the form of transparent sheets, one well-known type of which is "cellophane," cellulosic film. Ribbons, straws, and sausage casings are but a few of the products made by the viscose process.

The E. I. du Pont de Nemours and Company's "Fiber D" is a new rayon fiber with a high degree of permanent crimp and other characteristics now available only in wool. This new fiber appears promising as a substitute for wool in carpets, upholstery materials, wall coverings,

and other decorative fabrics. It is mothproof and takes readily to antimildewing and fire-retardant preparations.

A new continuous process for the production of rayon was started in 1940 in a huge plant, built after six years of research, at a cost of $11,500,000, by the Industrial Rayon Corporation at Painesville, Ohio; it represents one of the outstanding chemical engineering achievements of our generation. In this fourteen-acre, windowless, air-conditioned plant, 371,000 glass blocks were used. This is the first plant in which the rayon threads are formed, bleached, shrunk, prepared, dried, and twisted before being wound in bobbins for shipment.

*3. **Esters.*** Cellulose, when treated with a mixture of sulfuric and nitric acids, forms compounds with the nitric acid which are called "esters." Partially nitrated cellulose is called "pyroxylin." It dissolves in a mixture of alcohol and ether and other solvents to produce liquid court plaster, fingernail polish, and household cements. Photographic films are made from pyroxylin because it serves as an excellent base for the photographic emulsion. When heated with camphor and a little alcohol, pyroxylin produces a tough, doughlike, plastic mass which can be easily shaped. The products obtained by the evaporation of the alcohol in this plastic mass are sold under such trade names as "Celluloid," "Xylonite," and "Pyralin." Such nitrocellulose plastics may be obtained in practically every shade and hue, in beautiful transparent, translucent, mottled, opaque, and pearl effects. They are employed in the manufacture of such diversified products as toiletware, fountain-pen barrels, radio dials, optical frames, and buttons.

Incidentally, camphor, which originally came from the camphor trees in Formosa, is now synthesized from turpentine obtained from our southern pines, thus breaking what was once a Japanese monopoly. As recently as 1920, refined imported natural camphor reached $3.55 a pound; today refined synthetic camphor, medicinal grade, is selling for around 60 cents a pound, while the technical grade, used in plastics and photographic film, sells for only about 35 cents a pound. The importance of synthetic camphor can be appreciated when one knows that the manufacture of photographic film alone requires more than half a million pounds a year.

Lacquers are solutions of pyroxylin, with or without dyes or pigments. Their discovery revolutionized the painting industry and greatly aided in various manufacturing processes; for example, an automobile can now be finished with lacquer in a few hours, whereas it formerly required as much as three weeks for the older varnishes and enamels to dry by the slow processes of oxidation or baking.

Just as lacquers have partially displaced oxidizing oil products for finishes, various new fabrics are replacing the older materials produced by the oxidation of linseed and other drying oils. Oilcloth is made by coating a cotton base with linseed oil containing the desired pigment. Linoleum is a somewhat similar product to which has been added ground cork. Today canvas is coated or impregnated with pyroxylin solutions containing materials to impart flexibility or color and to produce durable fabrics, which are sometimes called "artificial leather" or "leather cloth." Frequently they replace leather and are treated so as to resemble leather. For many uses, such as book bindings, they are not only cheaper than, but also superior to, leather.

When cellulose is further nitrated, a somewhat different cellulose nitrate, called guncotton, is obtained. Guncotton, though a high explosive, is too bulky, because it retains the original form of the cotton from which it was made; and it is too dangerous to use because of its sensitiveness to shock.

In 1867 a Swedish chemist, *Alfred Nobel*, discovered that guncotton would dissolve in warm nitroglycerine, which in itself is an excellent explosive but difficult to handle because of its liquid state and too great sensitivity to shocks. It was found that the resulting mixture, containing a little acetone and vaseline, was less sensitive and could be used as a propellant powder. One such powder is the British "Cordite." While smokeless powder may be made in this way, it is usually made in the United States simply by "colloiding" the guncotton with ether and alcohol to form a homogeneous and amorphous dough. This dough is then forced through dies somewhat similar to a macaroni machine, but which, in the case of cannon powder for example, have seven axial perforations made in the cord. The cord is then cut off into short lengths two or three times its diameter. These are then dried to expel the solvent. Alfred Nobel also invented dynamite, which is a mixture of nitroglycerine and sawdust or infusorial earth. It is interesting to note that Nobel left his money, made from the invention of these powerful explosives, to establish five world-famous prizes in peace, literature, medicine and physiology, physics, and chemistry.

Rayon dresses could be made from pyroxylin, but they would be very dangerous to wear because, once ignited, they would burn very rapidly. Methods have been found to remove the nitrate radicals after the cellulose nitrate threads are formed so as to convert them into cellulose, which is no more inflammable than cotton or other types of rayon. This process is one of the less important rayon processes now in use.

All pyroxylin plastics suffer from the disadvantage of being extremely inflammable. It has been found that acetic acid can replace nitric acid in its action on cellulose and that the cellulose acetate thus produced is much less inflammable. Cellulose acetate is marketed extensively as dress fabrics known generally as "acetates." The so-called "safety" motion-picture films are made from cellulose acetate. Many difficulties in the preparation of cellulose acetate products had to be overcome, but they are now rapidly replacing pyroxylin lacquers and plastics. The E. I. du Pont de Nemours and Company's "Plastacele" cellulose acetate plastic is an example. It is used in such materials as airplane cowlings, decorative jewelry, musical instruments, lamp shades, watch crystals, steering wheels, combs, bottle caps, and safety glass.

FIG. 290. Two identical sheets of "Louverglas" placed at different angles. Above it appears as transparent sheeting; below it appears translucent. (Courtesy of the E. I. du Pont de Nemours Company.)

"Tenite" is a plastic material made from cellulose acetate and cellulose acetate butyrate by the Tennessee Eastman Company.

4. Ethers. The Dow Chemical Company manufactures ethyl cellulose under the trade name of "Ethocel." This product is an ethyl ether of cellulose resulting from the interaction of ethyl chloride and alkali cellulose. It is colorless, odorless, tasteless, stable to heat and chemicals, slow-burning, flexible, and tough. These and other desirable properties make it one of the most versatile of cellulose derivatives for the manufacture of coating compositions, films, and plastics.

FIG. 291. Telephone equipment made from Tenite. (Courtesy of the Tennessee Eastman Corporation.)

5. Decomposition Products. The production of charcoal by heating wood in an absence of air is an old industry. The by-products of this decomposition are acetic acid and wood alcohol (methanol). The synthesis of acetic acid from acetylene and the synthesis of wood alcohol (methyl alcohol) from carbon monoxide and hydrogen reduced the value of these

products so much that the destructive distillation of wood has been greatly curtailed.

Other processes for using cellulose as a raw material are being developed. For example, *Friedrich Bergius* has developed in Germany a commercial process for the production of edible sugars from sawdust. As the structure of cellulose becomes better known, it is certain that many other valuable materials will be made from it.

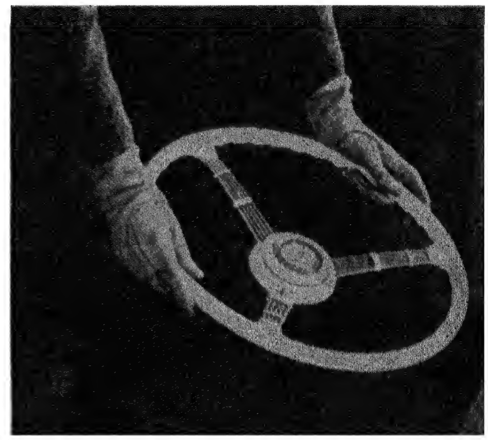


FIG. 292. The steering wheel of cellulose acetate is only one of 200 plastic parts on the modern automobile. (Courtesy of The Bakelite Corporation.)

Chemical Research Has Produced Materials Which Greatly Improve Fabrics Made from Natural Textile Fibers.

The sensational creation of synthetic fibers must not obscure the story of the brilliant achievements of chemistry in improving the commonplace textiles.

1. Water-repelling. Water repellency differs from waterproofing in that, while the whole surface is rendered impervious to water in waterproofing, the surface remains porous in water repellency because each fiber is waterproofed. Water repellents render fabrics such as hosiery resistant to spotting by water. One interesting new finish of this type is the E. I. du Pont de Nemours and Company's "Zelan" durable water repellent, which is so resistant to laundering and dry cleaning as to remain effective throughout the useful life of the fabric to which it is applied.

2. Snagproofing. Wax emulsions and resin finishes lubricate textile surfaces of hosiery, thus decreasing their tendency to snag.

3. Wiltproofing. Collars which retain their shape without the use of starch before ironing them are made possible by sandwiching cellulose acetate or other types of resins between layers of fabric.

4. Creaseproofing. Crease resistance is imparted to cotton, rayon, and linen by the use of urea-formaldehyde resins (described in the next Section).

5. Fire-retarding. The latest and most satisfactory fire retardant is ammonium sulfamate.

6. Mildewproofing. Salicylanilide, a coal-tar derivative, prevents mildew.

7. Mothproofing. Compounds of fluorine and chlorine which will mothproof textiles have been discovered.

8. Shrinkproofing. "Sanforizing," *i.e.*, preshrinking, has largely solved the problem of the shrinking of cotton textiles, and it is being introduced more and more widely.

Sulfuryl chloride prevents the shrinking of wool without injuring the fibers.

The treatment of textiles as outlined above leaves much to be desired, the most serious difficulty being that most of these processes are mutually exclusive. Research must be carried out to discover materials that will provide more of the above advantages for a single fabric.

Lignin, a By-product of the Cellulose Industry, Is One of Our Greatest Industrial Waste and Stream-pollution Problems.

Lignin is the noncarbohydrate portion of extractive-free, woody, plant tissue. Its chemical structure is not known. Fifteen million tons of lignin are available each year from sawdust, shavings, and other forms of wood waste. The wood-pulp industry must dispose of twelve million gallons of lignin solution each day. Millions of tons of lignin are available in such agricultural wastes as corncobs, grain hulls, bagasse, and waste straw. Such an enormous supply of lignin not only taxes our ingenuity in disposing of it but also challenges us to do the necessary research to discover its true chemical nature and utilize it as a raw material in the manufacture of still more "better things for better living."

Research already carried out shows that lignin may be used in the manufacture of plastics. Perhaps plastic boards may replace lumber in house construction some day, thus providing a beautiful, fire-retardant material which would require no protective coatings. Perhaps lignin research may meet the need for a cheap, wear-resistant flooring material. Other researches suggest the possibility of manufacturing lignin adhesives for use in road-building.

One interesting product now obtained from lignin is vanillin, used in making imitation "vanilla flavor" extracts.

STUDY QUESTIONS

1. What is cellulose?
2. What products are obtained from cellulose by simple physical changes?
3. Is the preparation of rayon a physical or chemical change?
4. Give the basic principles involved in the preparation of "cellophane."
5. Outline the processes which utilize cellulose to produce "better things for better living."
6. In what respects is the E. I. du Pont de Nemours and Company's slogan "better things for better living through chemistry" well illustrated in this Section?

7. List the products obtained from cellulose by dissolving and reprecipitating it.
8. How has cellulose been made into a digestible carbohydrate for human use?
9. What is rayon? What different characteristics may be imparted to rayon?
10. What is lignin, and why does it constitute a problem for research today?
11. What are the disadvantages of lumber that the chemist might try to eliminate either by treating the lumber or by producing new materials to replace it?
12. Mention two products discussed in this lesson which have had a distinct bearing upon our economic relationship with Japan.
13. Suggest some of the possible important and unexpected consequences of a possible widespread use of "throw-away" products similar to "Pervel" to replace cloth fabrics.

UNIT IX

SECTION 6

SYNTHETIC PLASTICS ARE OUTSTANDING EXAMPLES OF "BETTER THINGS FOR BETTER LIVING"

Introduction.

A *plastic*, or *resin*, is a material that can be molded into some desired shape. In the broadest sense these terms might include such materials as iron or glass, but in actual usage they refer to such natural products as rosin, gums, and amber, and to synthetic organic molding materials.

The first synthetic plastics were devised to replace such natural materials as amber, paraffins, tar, bitumens, asphalts, rubber, rosin, glue, shellac, gelatin, waxes, and copals. Thus celluloid was originally devised as a substitute for ivory. Synthetic plastics have opened up many new fields of usefulness in addition to those fields in which they have displaced natural products. Today plastics are replacing natural textile fibers such as silk or wool; they are replacing metals and wood in automobiles and airplane manufacture. In the building industry their hardness, beauty, and resistance to chemical change recommend them for many architectural purposes, from fireplace mantels to table and counter tops, protective paints and varnishes, molded hardware, and lighting fixtures.

Plastics decrease manufacturing costs because they can be molded into shapes which would require many costly operations to obtain from metals. The cast and laminated plastics can be easily turned and machined, are light in weight, strong, and free from the corrosion which is the enemy of metals. Their excellent insulating properties render them invaluable in the manufacture of a wide variety of electrical equipment.

The use of plastics has just begun.[1] It is safe to predict that plastics will be widely used within the next twenty years in the manufacture

[1] In 1939, 6966 workers pocketed $9,839,935 in wages earned in the production of $77,653,314 worth of synthetic resins. The production of coal-tar resins jumped from 131,568,162 pounds in 1937 to 152,121,989 pounds in 1939.

of flooring, furniture, prefabricated houses, basins, tubs, ducts, dishes, and tableware. Many of these applications merely await the perfection of manufacturing processes, the lowering of the cost of production, and the development of distributing agencies.

The Fourteen or More Different Major Types of Plastics May Be Classified Under Three Main Types.

1. Rigid, thermosetting materials. Phenol-formaldehyde and urea-formaldehyde plastics are examples of those types of synthetic resins which, once hardened by heat, cannot be softened by heating again.

2. Rigid thermoplastics. Examples of rigid plastics which can be softened by heating and re-formed are the cellulose esters and ethers, methyl methacrylate, polystyrene, vinylidene chloride, and polyvinyl esters.

3. Flexible elastic thermoplastics. Examples of flexible thermoplastics are rubber hydrochloride, vinylidene chloride, and the plasticized polyvinyl esters. One might include in this group the plastics especially adapted for the preparation of textile fibers, nylon, and vinyon. Synthetic rubbers and rubber substitutes also belong to this group of plastic materials.

Synthetic plastics may also be classified as to their method of preparation; and from this viewpoint two types may be distinguished, namely, the polymerization and condensation plastics, or resins as they are often called. Polymerization plastics result from the building of large molecules by the interaction of smaller ones of the same kind or of different kinds. In the latter case the product is called a *copolymer.* Condensation products result from the interaction of two or more different compounds which yield new molecules of an essentially different type plus water. In many instances both types of reactions take place simultaneously.

"Bakelite" Was One of the First Synthetic Plastics.

In 1909 an American chemist, *Leo H. Baekeland*, announced a synthetic plastic which he called "Bakelite" phenolic resinoid. This synthetic resin was produced by heating phenol with formaldehyde in the presence of a catalyst. Today phenolic resinous products in a variety of forms are noted for their strength, chemical resistance, and electrical insulating properties. Phenolic resins may be used in the form of a varnish to protect or insulate metal surfaces. Paper, canvas, and other fabrics may be impregnated with them and then heated under pressure to produce very tough materials, such as radio panels, automobile gears, and heavy-duty bearings. Mixed with wood flour,

asbestos, or other inert fillers, they are used to produce various molded products such as instrument cases, electric-iron handles, telephone handsets, fountain pens, handles, radio cabinets, and a thousand other things that are so common today. Phenolic resins are used as adhesive bonds to cement together the layers of wood in the modern resin-bonded plywoods to yield a product which is resistant to moisture and is not attacked by fungi and other wood-destroying agents. These plywoods may, therefore, be used in the construction of doors and outside surfaces of buildings and even airplane fuselages.

"Bakelite" phenolic materials were the forerunners of many synthetic plastics, some of which have already been discussed in Section 5 of this Unit. Today plastic products sold under the trademark "Bakelite" include a wide variety not only of phenolics, but also of ureas, acetates, and polystyrenes.

The demand for phenol for the manufacture of plastics and other products has far exceeded that obtained directly from coal tar. In 1940 the Durez Plastics and Chemicals Company opened a $2,000,000 synthetic phenol plant capable of producing 15,000,000 pounds of phenol a year. The Dow Chemical Company and the Monsanto Chemical Company have still larger units in operation. Automatic operation has been achieved to the point where only six men are required per shift to operate the plant. The amount of phenol obtainable directly from coal tar has not been able to meet increasing demands, so benzene, a much more abundant fraction obtained in the distillation of coal tar, is utilized as the raw material to produce phenol in this plant. The process involves the treatment of benzene with hydrochloric acid in the presence of a catalyst. The chlorobenzene thus obtained is then hydrolyzed with steam to produce phenol.

Urea, casein, soy bean protein, zein, and other materials may replace the phenol first used by Baekeland in making plastics, while furfural, acetal, and other aldehydes may replace the formaldehyde. "Durite" is a typical phenol-furfural resin. A new plastic material made from urea and formaldehyde is very interesting because it is water-soluble and sets within a few days without heating to form a waterproof material that has a wide use as a binder for plywood.

Furfural Is an Industrial Chemical Obtained from Agricultural Wastes.

Furfural possesses many advantages over formaldehyde in the manufacture of plastics, and for many years after the process of obtaining it from waste cellulosic material, such as corncobs, rice, cottonseed hulls, and peanut shells, was perfected in 1922, the synthetic-plastic industry was furfural's chief customer. Today, however, the use of

furfural in plastics is eclipsed by its use as a solvent in the refining of lubricating oil. Solvent refining of motor oils removes the materials that cause instability under extreme conditions of heat and oxidation and an objectionably high viscosity-temperature coefficient, thus cutting down on sludge formation and difficult starting of motors in cold weather.

Thirteen billion pounds of furfural could be produced annually from the raw materials now wasted. The price of furfural is now only nine cents per pound. New large-scale uses will make possible a lower price, and this lower price will then result in a more extensive use of this material. Furfural now challenges the chemist to put it to work.

Polystyrene Plastics Typify the Intensive Industrial Research Required for the Successful Development of Plastics.

Polystyrene (trade names include "Bakelite" polystyrene and "Styron") has been known since 1839, although it was not introduced commercially until one hundred years later. The ethylbenzene process now used in making this type of plastic was discovered in 1869 by the great French chemist *Bertholet.* As early as 1911 several companies became interested in the manufacture of polystyrene plastics, but a host of baffling production problems prevented its commercial development. The cost of production was too high, and difficulty was experienced in obtaining materials of sufficient purity.

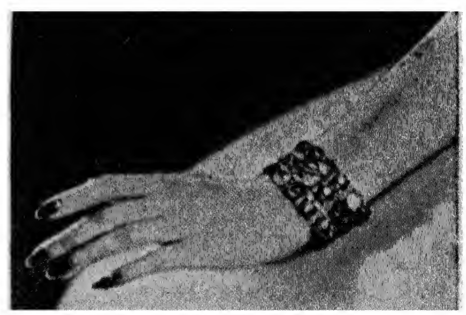


FIG. 293. Beautiful transparent gems from polystyrene can be obtained in any color, crystal, ruby, amethyst, emerald, and topaz. Polystyrene is employed for the production of gems because of its clarity and its high index of refraction. (Courtesy of the Bakelite Corporation.)

Extensive research by the Dow Chemical Company finally made it possible to produce improvements in the quality and purity of the product and introduced new economically feasible processes of manufacture.

Polystyrene plastic is sold under the name of "Lustron" or "Lumitile" in the form of building tiles, which offer wide possibilities to architects in planning new decorative lighting effects.

Polystyrene plastics are produced by the polymerization of the product of the reaction of benzene with ethylene. Benzene, as you will recall, is obtained from coal tar, while ethylene is obtained principally by the cracking or destructive heating of aliphatic hydrocarbons recovered from petroleum gases.

Moldings of crystal-clear transparency are used as instrument faces, chemical-resistant bottle caps, combs, high-frequency radio parts, buttons, and radiant, colored gems for costume jewelry.

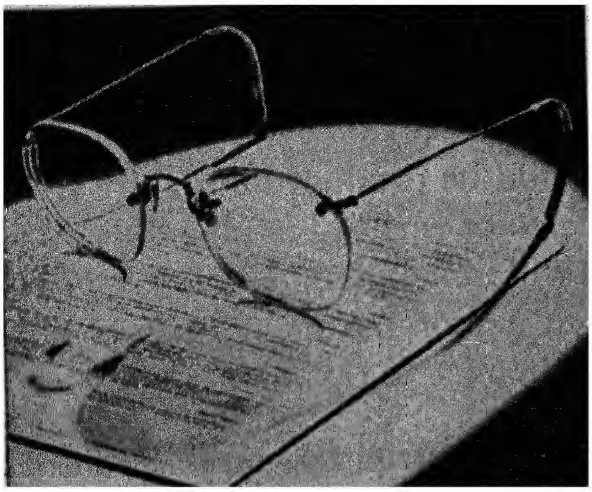


FIG. 294. Polystyrene lenses. (Courtesy of Science Service.)

In England in 1941 polystyrene was used to produce unbreakable, scratchproof lenses for spectacles for the troops. These lenses were made with the aid of eight thousand different dies so that lenses could be supplied for almost every conceivable defect of vision. Each soldier was issued two spectacles, one for use under his respirator, and another for ordinary use.

Polyvinyl Resins Are Obtained from Salt, Coal, Lime, and Air.

A series of polyvinyl esters are manufactured by the Carbide and Carbon Chemicals Corporation and sold under the trade-mark "Vinylite." They may be classified as follows:

Series A — Polyvinyl acetate
Series Q — Polyvinyl chloride
Series V — Copolymer of vinyl chloride and vinyl acetate
Series X — Polyvinyl butyral

The E. I. du Pont de Nemours Company manufactures polyvinyl butyral and sells it under the name "Butacite."

A copolymer resin of the proper chloride-acetate ratio can be produced in the form of fibers as fine and virtually as strong as silk, but more elastic, waterproof, and creaseproof. Such fibers are sold under the trademark "Vinyon" and replace natural silk for many uses.

"Vinyon" fiber may be used for hosiery, gloves, bathing suits, fishing lines, sewing threads, shower curtains, woven filter cloth, fiber-bonded felt, woven shoes, and chemical-workers' clothing. It is prepared by polymerizing vinyl halides, such as vinyl chloride, with vinyl esters, such as vinyl acetate.

Polyvinyl acetal resins are thermoplastic, colorless, glass-clear, tasteless, odorless, low in density, and slow-burning. They may be dissolved in organic solvents such as methanol, and they may be emulsified in water. They produce durable, wear-resistant films, unaffected by oxygen or aging. They are used for adhesives in the manufacture of such products as drinking cups, cartons of various types, and shoes;

for textile sizing and stiffening; for sizing and imparting transparency to paper; and to make lacquers and paints. Polyvinyl butyral, formed from polyvinyl acetate by hydrolysis and condensation with butyraldehyde, is used as an interlayer sandwiched in between plate glass to form laminated safety glass. The plastic layer stretches under a blow and holds the broken pieces of glass together.

FIG. 295. A Vinylite fabric work jacket. (Courtesy of the Carbide and Carbon Chemicals Corporation.)

One of the most important uses of "Vinylite" resins developed recently is in lining "tin" cans for beverages. "Vinylite" resin-lined cans completely protect the delicate flavors in beverages and foods, and today many well-known canned products retain their distinctive flavors because of this transparent coating of "Vinylite" resins.

"Vinylite" resinous products have come to be known as the "versatile plastics" because their unusual characteristics permit such a wide range of applications.

Vinyl chloride is made from acetylene, which is derived from calcium carbide (coal and limestone), and hydrogen chloride, which is obtained from salt and water. Vinyl chloride is also made from ethylene dichloride, which in turn is synthesized from cracked petroleum gases and chlorine. Acetic acid used to produce vinyl acetate may be obtained from acetylene or natural gas.

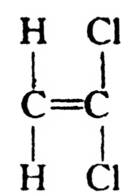
These vinyl resins have a wide range in composition and properties inasmuch as their molecular weights range from 6000 to 25,000, depending upon the number of molecules that have joined each other in the polymerization process.

"Vinyon" fiber is now used to manufacture felt without fur or wool, in which cotton fibers are mixed with "Vinyon" fibers and then heated to produce a weblike bonding of the cotton fibers by the "Vinyon" fiber. Such felts have been found to produce superior filtering media for filtering liquids and air.

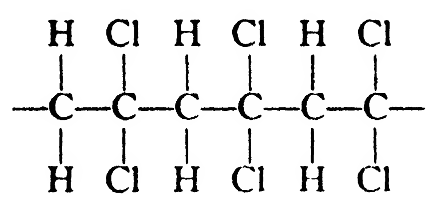
The copolymerized resin is unique because the acetate, with its lower softening-point, renders the copolymer internally plasticized. Thus

compounds from the copolymer require very little or no plasticizer,[1] whereas most other synthetic resins require considerably greater quantities of plasticizing agents to make compounding and forming possible.

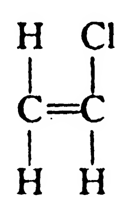
Vinylidene chloride



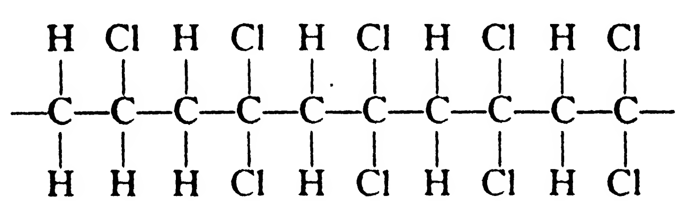
may be polymerized to produce long-chain compounds such as



A wide range of properties may be obtained by controlling the length of the chain or by adding another vinyl-type substance such as vinyl chloride



In this case the two substances polymerize together, forming such chain compounds as



Such vinylidene resins are sold under the name of "Saran." They are used as binders for abrasive wheels, fishing leaders, and heavy-duty upholstery materials. Saran is highly resistant to chemicals, will not burn, and is odorless, tasteless, and nontoxic. It has extreme tensile strength and high abrasion resistance and toughness.

Vinyl chloride may be polymerized by itself to produce a resin, but, as mentioned above, the addition of vinyl acetate confers many additional desirable properties. Glycolates, phthalates, or abietates are added to these resins to give them still more flexible, resilient, and

[1] See p. 681.

elastic qualities. Such added substances are called *plasticizers*. In this way strong, tough, durable, washable, beautifully clear, elastic sheets may be prepared from vinyl ester resins. These elastomeric sheets can be cut and sewed like any textile and may be joined by solvent or heat sealing.

Such products as belts, suspenders, garters, watch straps and chains, and even wallets have been made of such "Vinylite" flexible sheeting. Two other uses for this sheeting are in air-conditioning ducts and collapsible tubes. They possess strength, durability, good appearance, novelty, and comfort. Comfortable and long-wearing shoes are made for both men and women. Such shoes would not require the "shining" that leather shoes do.

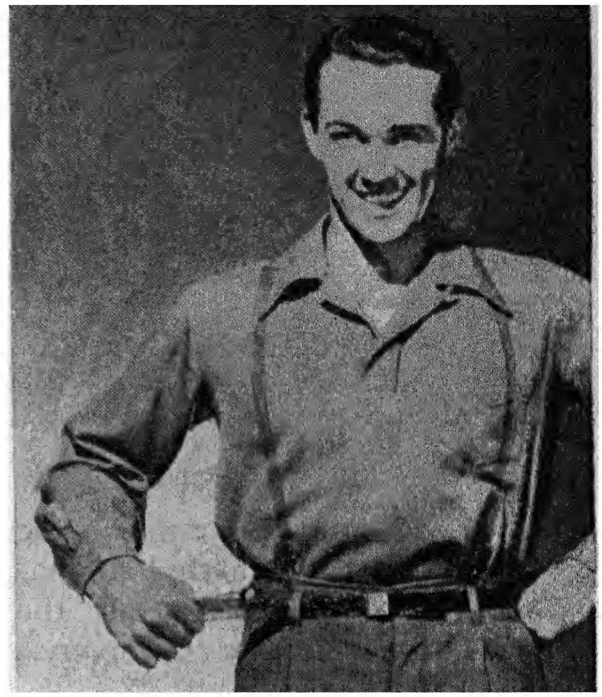


FIG. 296. Elasticized Vinylite sheeting belt. (Courtesy of the Carbide and Carbon Chemicals Corporation.)

There may be added to the above list of uses umbrellas, cosmetic bags, shoe bags, laundry bags, shower curtains, bridge-table covers, draperies, bedspreads, crib and bed sheeting, bibs, bathing suits, razor straps, and dog collars.

Polyvinyl Alcohols Are Also Obtained from Coal, Air, and Water.

Polyvinyl alcohols are white powders, odorless and tasteless. They are used as adhesives and paper coatings to give such strength to paper towels that they may be soaked in water, squeezed, twisted, and pulled with relatively little deformation. Paper containers may be greaseproofed and sized with polyvinyl alcohols. This material is also used as a softener and transparentizer in making glassine paper.

As an adhesive polyvinyl alcohols are interesting because of their freedom from odor, color, taste, and attack by bacteria. They are used to manufacture white shoe dressings that will not rub off, pigmented inks, paints, water colors, printing pastes, etc. They also form tough, elastic, water-soluble films on metallic surfaces. They may be extruded to form tubes, rods, sheets, or threads. Tubing made from polyvinyl alcohols is impervious to oils and solvents and is resistant to flexing and vibration. Such tubing may thus replace metal tubes for fuel and oil lines in airplanes. Polyvinyl alcohol tubes transmit sound

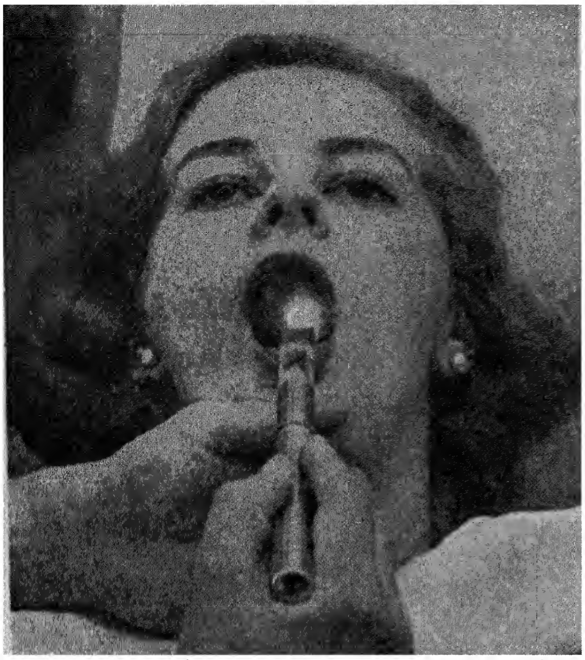


FIG. 297. A tongue depressor made of curved "Lucite" methyl methacrylate plastic. (Courtesy of the E. I. du Pont de Nemours Company.)

with minimum distortion and are thus used in transmitting speech through flexible conduits.

Polyvinyl alcohols are used in photolithographing printing. A solution of polyvinyl alcohols, sensitized to light by adding ammonium or potassium dichromate, is coated on a zinc plate. This plate is then "exposed" like other photographic plates and developed by simply washing in water. The nonexposed portions are soluble in water, while the exposed portions are rendered insoluble by the action of the light and remain on the plate to form the printing surface.

Polyvinyl alcohols may be used as an emulsifier in making such cosmetic products as cold creams, brushless shaving creams, cleansing creams, and beard-setting preparations for use with electric razors. They also increase the sticking and spreading power of insecticide sprays and, when coated on glass, make it nonfogging under conditions of high humidity inside and low temperatures outside of a room.

"Super-glass" Is Now Made from Polymethyl Methacrylate.

A few years ago one of the felt needs was an organic "glass." Today we have in polymethyl methacrylate a product clearer than optical glass, weighing half as much, which may be cut, turned, sawed, carved, drilled, polished, shaped, formed, and swaged. It is flexible, durable, and strong, and may be given translucent, opaque, or pearl color effects. This product, sold under the names of "Lucite" methyl methacrylate plastic, "plexiglass," or "Crystalite," is derived ultimately from air, water, and coal or

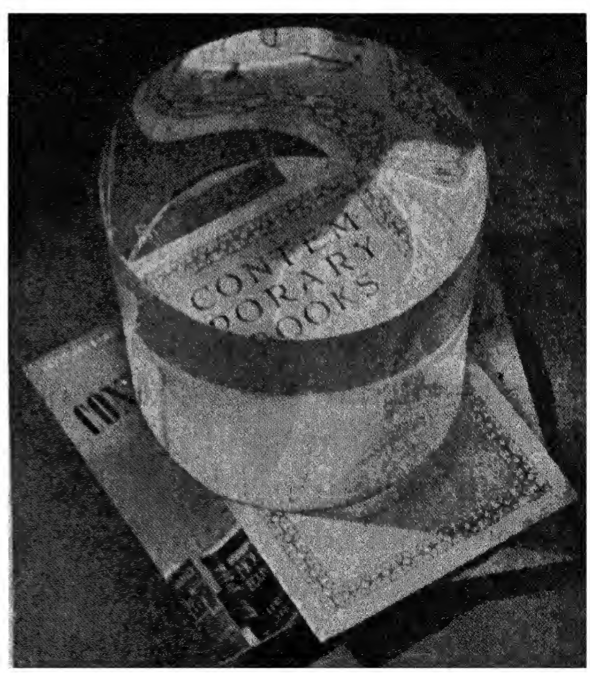


FIG. 298. Printed material shown through a 9½ inch thickness of "Lucite" methyl methacrylate plastic. (Courtesy of the E. I. du Pont de Nemours Company.)

natural gas. The usual raw materials employed in producing acrylic acid derivatives are ethylene chlorhydrin and acetone, which are obtained from the hydrocarbons contained in the gases produced in the cracking of petroleum.

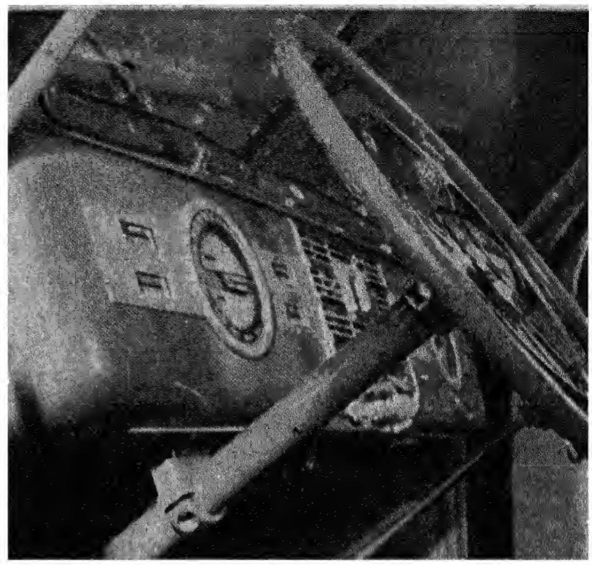


FIG. 299. Dashboard of car with panels of "Lucite" methyl methacrylate plastic. (Courtesy of the E. I. du Pont de Nemours Company.)

It transmits light through its own curves, while conducting practically no heat, and thus finds applications where light is to be "piped" in medical and dental appliances. It is used in making automobile reflectors, furniture, shoes, dashboard panels, radiator ornaments, vanity cases, and a host of other products.

Lenses for cameras and eye glasses can be made by molding them out of this plastic material much cheaper than optical glass can be ground, but they were not yet in commercial production in 1941.

This type of plastic is thermoplastic and may be bent and shaped by softening it in hot oil at temperatures varying from 285° F. to 315° F.

Soya Beans and Milk Now Compete with Coal as a Raw Material in the Production of Plastics.

Two Japanese chemists have produced from soya beans a strong synthetic fiber which shows a possibility of competing with silk and wool.

Italy was the original home of synthetic wool fibers, made from casein, the protein of milk. This product is called "lanital." To produce "lanital," casein is dissolved in an alkaline solution, aged, and extruded into an acid bath, where it is precipitated. It is then hardened with formaldehyde. Lanital is very similar to wool in some respects. Casein wool is marketed in the United States under the name "Prolon."

Casein has been combined with formaldehyde to make plastics for billiard balls, buttons and buckles, and other products.

An average cow produces enough casein each year to produce one hundred pounds of lanital.

Fifteen million pounds of casein are used each year for the preparation of casein paints.

The Ford Motor Company has developed a fiber from soya beans,

for use in automobile upholstery. It is prepared in much the same manner as is "Lanital."

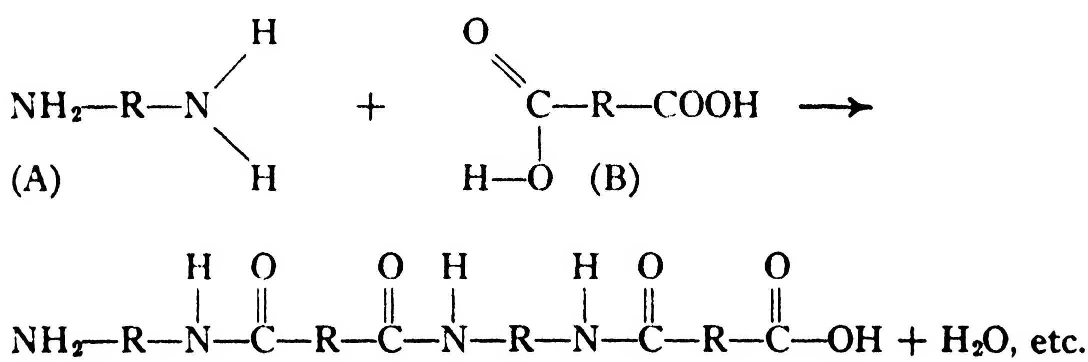
The United States Bureau of Dairy Industry has developed methods of producing acrylic acid ester plastics from lactic acid obtained from whey.

Another type of protein fiber is produced from zein, which is derived from corn meal. The zein solution is extruded through spinnerets into a coagulating bath containing an aldehyde such as formaldehyde to harden the fiber.

Polymeric Amides Are the First Industrial Synthetic Protein-like Materials.

Polymeric amides are derived from coal, air, and water and are characterized by extreme toughness and strength. Nylon is the generic name which the E. I. du Pont de Nemours Company coined for these polymeric amides, which are the scientist's challenge to the silkworms and the bristle-bearing hogs of the Orient.

The essential reaction is



When any primary or secondary amine (such as A in the above equation) unites with any dicarboxylic acid (such as B in the above equation), nylon is formed. A typical example would be the polymer formed from pentamethylene diamine and sebacic acid. The simplest way to prepare a nylon would be by the interaction of molecules of an amino acid. These protein-like materials are entirely new; they are not known to have any counterpart in nature.

The original discovery that led to the production of nylon was made in connection with fundamental research on polymerization. After two years' work in this research, one of the research chemists noted that a long fiber was formed as he attempted to remove the product from one of the stills.

Nylon is given its elastic properties by stretching it after it has cooled. This stretching process causes the molecules to orient themselves end to end, thus bringing the molecules so close together that

powerful intermolecular forces which resist slipping when the material is stretched, are developed.

While it is true that one type of nylon may be obtained from coal, air, and water and while it is also true that these raw materials are very abundant and cheap, it does not follow that nylon products should be cheap. On the contrary, many intricate chemical reactions must be carried out, using elaborate and costly equipment and requiring rigid control from start to finish.

Nylon can be used to coat paper, to make oilproof containers, to coat leather to make an excellent patent leather, to coat cloth to produce flexible waterproof clothing, to coat wire mesh to produce a clear, strong glass, and to make parachutes, upholstery, men's suit linings, rugs, carpets, and lace.

FIG. 300. Nylon in large diameters such as used in surgical sutures, fishing leaders, and bristles for brushes. (Courtesy of the E. I. du Pont de Nemours Company.)

Nylon fibers may be crimped to produce wool-like fibers which rival the heat-insulating properties of wool and are superior to wool in strength, dyeing characteristics, elasticity, mothproofness, and immunity to harm from cleaning processes.

Polymeric amides in the form of relatively coarse monofilaments may be used to produce synthetic bristles which possess the advantages of being uniform in quality, extremely tough, wetproof, and springy. Such bristles are used in a wide variety of both toilet and industrial brushes. Nylon monofilaments are also used for fishing leaders and lines, surgical sutures, and strings for tennis and badminton racquets. Toothbrushes with nylon bristles have been in good condition after two years of daily use. Nylon hairbrush bristles have stood up equally well.

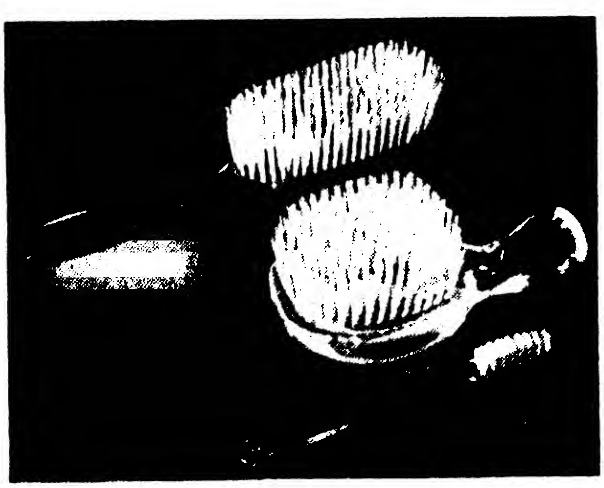


FIG. 301. Nylon bristles. (Courtesy of the E. I. du Pont de Nemours Company.)

Polymeric amides have also been used to produce a photographic film base which is superior to cellulose nitrate and cellulose acetate in that it has greater resistance to water, greater strength, and flexibility. These new films are noninflam-

mable, and they may be made half as thin as ordinary films, thus reducing distortion of images in color photography. These films need not be stored under carefully adjusted atmospheric conditions.

Nylon is only one example of the products developed by the E. I. du Pont de Nemours Company through systematic and continuous research over a period of many years. While large sums of money have been spent on research — some of which may be thought of as wasted in that no useful product was developed — the useful and practical products which have resulted from this research are of such value to our industrial and national life as to be worth all it cost to develop them.

Among the more important E. I. du Pont de Nemours Company's products of recent years are the following:

1923 — Quick-drying nitrocellulose lacquers.
1927 — Moistureproof "Cellophane" cellulose film.
1928 — "Dulux" synthetic resin enamels.
1929 — Acetate rayon.
1931 — Titanium pigments.
1932 — Neoprene synthetic rubber.
1933 — Synthetic camphor.
1934 — Heat-resistant rayon for tire cords.
1935 — Synthetic urea for fertilizers and plastics.
1936 — Acrylic acid plastics and resins.
1938 — "Zelan" durable water-repellent finish.
1939 — Nylon.

The E. I. du Pont de Nemours Company's first plant for the production of nylon yarn went into production late in 1939, and a second plant was scheduled to be completed during 1942. The total capacity of these two plants was planned to amount to about 16,000,000 pounds of nylon yarn per year.

In addition to hosiery for both men and women, nylon yarn is also being used for dress fabrics, gloves, ties, raincoats, umbrellas, shower curtains, and sewing thread. It has also been found promising for parachutes and a wide variety of other purposes.

Other Types of Plastics Are Being Developed.

In 1940 the American Cyanamid and Chemical Corporation developed a new type of "alkylated aminealdehyde resin" for coatings. Such resins are called "melamine resins."

Methods for the production of plastics from the proteins of alfalfa and from sawdust, aniline, and furfural have been worked out.

White hydrocarbon resins have been prepared from naphthalene,

which is one of the products obtained from the destructive distillation of coal.

Piccolyte is a resin made by the polymerization of terpenes, while Piccoumaron is made from coumarone.

Nypene resin has been developed from turpentine raw materials.

Maleic anhydride is used in the preparation of such resins as the glycol maleates.

The alkyd, or rezyl, resins have already obtained an important place in the plastic world. These resins are obtained by condensing phthalic acid (a coal-tar product) with glycerine. They are particularly valuable as electric insulators. "Glyptal" and "Dulux" resins are typical alkyd resins.

"Halowax" chlorinated naphthalene products were invented by *Thomas A. Edison* for use in the manufacture of his phonograph records.

STUDY QUESTIONS

1. Discuss plastics as to (*a*) classification, (*b*) methods of preparation, (*c*) raw materials, (*d*) properties, and (*e*) uses.
2. What is meant by (*a*) condensation, (*b*) polymerization?
3. What is a copolymer? Give an example.
4. What is the function of a plasticizer in the manufacture of plastics?
5. Discuss the preparation and properties of (*a*) styron, (*b*) vinyon, (*c*) nylon, (*d*) lanital, (*e*) exton, (*f*) neoprene, (*g*) "Lucite," (*h*) "Bakelite."
6. Discuss some of the raw materials which may replace coal as a raw material for the synthesis of plastics.
7. Try to predict some of the future applications of plastics.
8. Why are plastics of so much value for better living?

UNIT IX

SECTION 7

COAL HAS BECOME A PROLIFIC SOURCE OF "BETTER THINGS FOR BETTER LIVING THROUGH CHEMISTRY"

> There's hardly a thing that a man can name
> Of use or beauty in life's small game
> But you can extract in alembic or jar
> From the "physical basis" of black coal tar —
> Oil and ointment, and wax and wine,
> And the lovely colors called aniline;
> You can make anything from salve to a star,
> If you only know how, from black coal tar.
>
> — *Punch*, London.

Introduction.

In 1919 the United States Senate Finance Committee held hearings on the serious question: Should the United States Government "promote the establishment of the manufacture of coal-tar products in the United States?"

Marston Taylor Bogert, Professor of Chemistry at Columbia University, testified before the committee that "a well-developed synthetic dye-stuffs industry is absolutely necessary for the security of our country." Twenty years later, as the result of an intensive program of chemical research, we find the United States one of the leaders in the production of a host of new synthetic dyes, pharmaceuticals, flavors, perfumes, and other products which have caused some people to designate the present as the Chemical Age. In 1914 we made only 10 per cent of our dyes, while in 1940 we produced about 95 per cent of our dyes and exported more than 25,000,000 pounds.

Among the outstanding better things for better living which are made from coal through chemistry are the synthetic plastics, discussed in Section 6. The other types of products made from coal will be discussed in this Section.

Coal Tar Is the Main Raw Material for Many Synthetic Products.

When soft (bituminous) coal is heated in the absence of air to produce coke, tar is one of the by-products. Previous to the World War

of 1914–1918 much of this tar produced in the United States was thrown away. Germany, to be sure, had learned how to use coal tar, but it required the World War to teach the rest of the world that coal tar is one of the most useful things in the world.

When coal tar is fractionally distilled, a number of materials are obtained which form the starting-point for the synthesis of dyes, drugs, perfumes, flavors, high explosives, and photographic developers. Figure 302 shows only a few of the products that may be obtained from benzene, for example, by well-understood chemical reactions.

As an example of the ramifications of the coal-tar industry, let us consider phenol (carbolic acid). Phenol, an antiseptic itself, may be treated with nitric and sulfuric acids to produce picric acid, which is not only an excellent disinfectant but also a brilliant yellow dye as well as a high explosive. A study of Fig. 302 will show how phenol is converted into such important drugs as aspirin, salicylic acid, phenacetin, and "Salvarsan."

Synthetic Perfumes and Flavors Now Replace Natural Products.[1]

Centuries ago adventurous merchants braved unknown deserts and uncharted seas to search the world for rare perfumes, spices, and drugs because of the high prices they would bring. The chemist has analyzed perfumes and flavoring materials and can consequently duplicate, although still imperfectly, most of the natural products at a much lower cost. At the same time he has produced a large number of perfumes previously unknown. Thus wintergreen flavor can be prepared before your eyes in five minutes by simply heating salicylic acid and methyl alcohol with sulfuric acid. Isoamyl acetate is known to be the principal constituent of pear flavor, while ethyl butyrate is the principal constituent of pineapple flavor. Such essential oils as jasmine, orange blossom, musk, heliotrope, tuberose, and ylang-ylang can now be synthesized from coal-tar compounds.

Coumarin, which is used in perfumes having the "new-mown hay" odor and as a substitute for vanilla in cheap extracts, can now be synthesized. Vanillin, the chief flavoring ingredient of vanilla beans, is synthesized today on a large scale.

Originally all perfumes were powders, gums, scented oils, or water or wine in which flowers had been steeped. In the tenth century, the Arabian doctor *Avicenna* first introduced distillation to concentrate

[1] The average *annual* increase in flavors and perfumes between 1919 and 1937 was 29 per cent; in photographic chemicals, 22 per cent. Total coal-tar finished products showed an average annual rise of 18 per cent. . . . Compare this with the average annual increase in automobile production of 9.6 per cent.

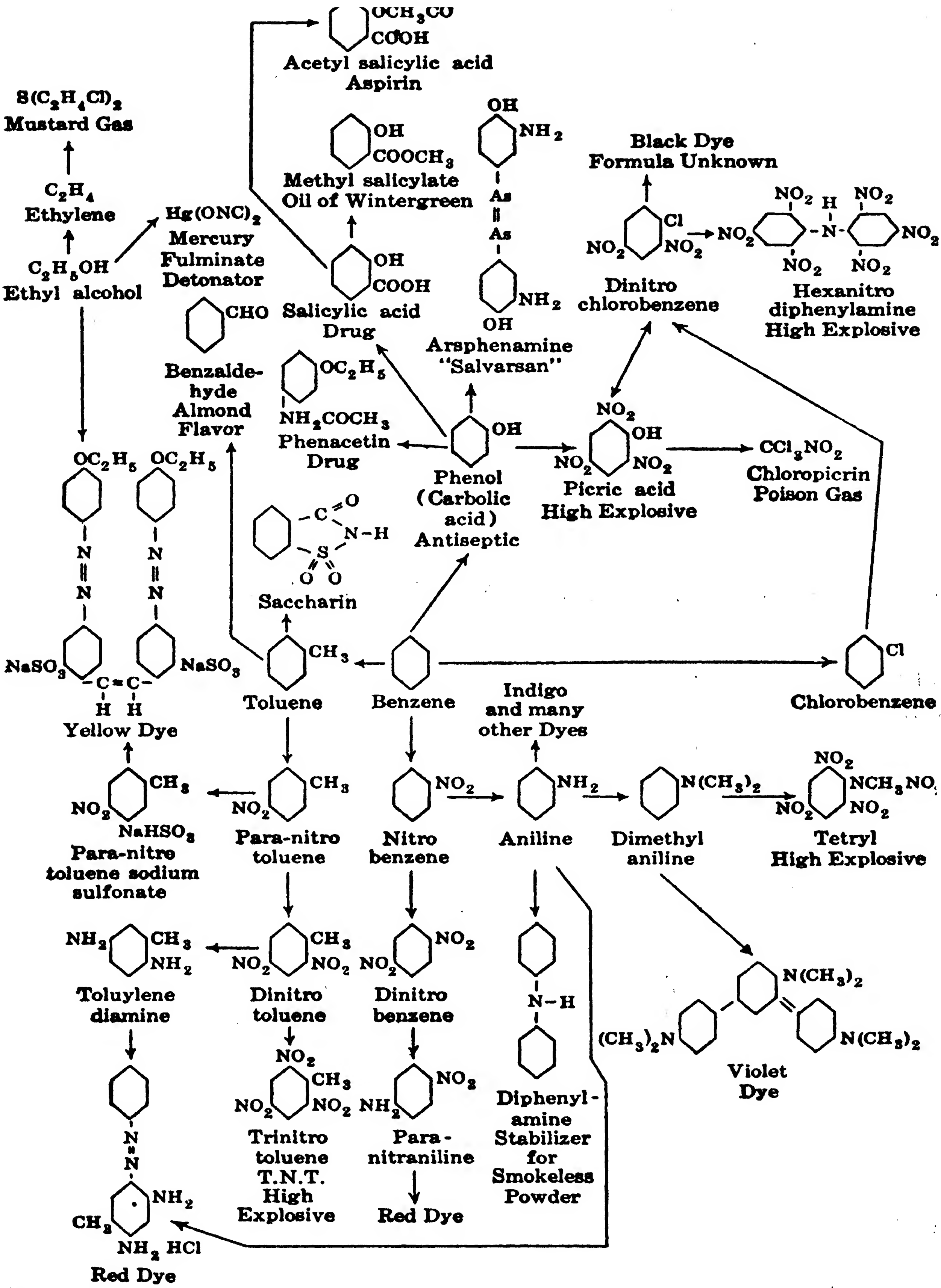


FIG. 302. A few of the interrelationships among aromatic chemical compounds.

perfumes. Today coal tar is the chief source of our perfumes. It is possible to duplicate any natural perfume, once its composition is known, but inasmuch as thirty or forty ingredients must often be skillfully blended to produce a given perfume, one can understand why cheap perfumes, which contain only a few ingredients, do not have the quality of odors equal to perfumes of more complex nature.

In 1939 the E. I. du Pont de Nemours Company produced a synthetic musk, which has the extraordinary properties of natural musks in fixing a perfume. (Fixing means causing a perfume to remain on a material for a relatively long time.)

Dyes.

The development of synthetic dyestuffs had its origin in *William Henry Perkin's* accidental discovery of mauve in 1856 during his research on quinine. Today the chemist synthesizes from coal-tar products dyes which are very much cheaper than the inferior natural colors which they replace. The famous Tyrian purple obtained from shellfish was so expensive that only kings could afford it, and purple came to be considered the badge of royalty. This dye was obtained from tiny sacs behind the heads of a kind of shellfish of the eastern coast of the Mediterranean Sea. In 1909 *Friedlander* analyzed this dye and found that it had already been synthesized and discarded because of its inferiority to other dyes never found in nature. Any dye found in nature can be duplicated and prepared in a purer condition in the laboratory once its composition has been determined. The knowledge of its composition is like an architect's blueprint, for anyone who understands the methods of building molecules can follow the plan once it becomes available. The analysis of dyes is not a simple process. Thus the Badische Anilin und Soda-Fabrik spent $5,000,000 and seventeen years in chemical research learning to make indigo. Then they reduced the price from $4 a pound to 15 cents a pound and received over $12,000,000 a year from their sale of this one dye. Not only is synthetic indigo cheaper, but it is purer and more uniform than vegetable indigo. Previous to the synthesis of indigo, it had been obtained from India, where nearly a million acres produced an annual crop valued at about $20,000,000. Within less than twenty years this profitable industry was wiped out.[1] Though it was a loss to India, it was a gain to the world.

Today man has available thousands of dyes which can duplicate any shade found in nature and are more suitable for use. Most of

[1] J. G. Crowther says that a million native workers in India and Burma died of starvation as a result!

these dyes are prepared from compounds obtained from coal tar and are therefore frequently called the "coal-tar dyes."

Among the dozen or so primary products obtained from the destructive distillation of coal tar are benzene, toluene, xylene, phenol, naphthalene, and anthracene. Certain dyes are made from anthracene and naphthalene and are therefore known by these names. The best-known dyes are the aniline dyes. Aniline, the intermediate from which these dyes are prepared, is made by treating benzene with nitric acid to replace an H with an NO_2 group, which is then reduced, the O_2 of the NO_2 group being replaced with H_2. In this way the chemist changes and builds molecules, sometimes of great complexity.

Certain groups of atoms which the chemist calls "chromophores" and "auxochromes" must be present to produce a color. The azine dyes, which include safranine, induline, nigrosine, and aniline black, all contain the group $\left\langle\begin{array}{l}N= \\ \\ N=\end{array}\right.$, while the triphenylmethane family, which includes such dyes as magenta, methyl violet, and malachite green, all contain the group $=C_6H_4=$.

Thirteen years after Perkin made his original discovery, he synthesized alizarin (Turkey Red), formerly obtained from madder root. Within a few months after the first synthesis of alizarin the process was developed on a commercial scale, and within a few years the sale of artificial alizarin reached $8,000,000 annually. At the same time the French people who had been raising madder for a living were forced to seek new employment, and the French Government was dependent on Germany for the dyes for the red trousers of her soldiers.

In 1878 the azo-scarlets were synthesized and were soon produced so cheaply that cochineal bugs no longer served as an economical source of these dyes. Thus England, in her turn, became dependent upon Germany for the dyes for the uniforms of her soldiers.

Today, thanks to a well-developed coal-tar chemical dye industry in the United States, there is available a wide range of synthetic dyes far superior to and surpassing in beauty, brilliance, fastness, and variety of hue those found in nature. Some dyes, called *direct* dyes, are especially adapted to combine with such fibers as silk or wool, and others, called *mordant* dyes, require a third substance (mordant) to bind the dye to the textile material.

Certain dyes will stain microorganisms, thus making it easier to examine them with a microscope, while other dyes are used as disinfectants, antiseptics, and in chemotherapy, as described in Unit IX, Section 6.

Coal and Lime Are Used to Prepare Calcium Carbide, Which Is the Starting-point for Many Important Organic Reactions.

Calcium carbide is prepared by heating coke with lime in an electric furnace.

$$\underset{\text{lime}}{CaO} + \underset{\text{coke}}{3\,C} \longrightarrow \underset{\text{calcium carbide}}{CaC_2} + \underset{\text{carbon monoxide}}{CO}$$

Calcium carbide and water react to form acetylene:

$$\underset{\text{calcium carbide}}{CaC_2} + \underset{\text{water}}{2\,H_2O} \longrightarrow \underset{\text{acetylene}}{C_2H_2} + \underset{\text{calcium hydroxide}}{Ca(OH)_2}.$$

Two molecules of acetylene may be polymerized in the presence of a catalyst to produce monovinyl acetylene, C_4H_4:

$$\underset{\text{acetylene}}{2C_2H_2} \longrightarrow \underset{\text{monovinyl acetylene}}{C_4H_4}$$

Monovinyl acetylene reacts with hydrogen chloride to produce chloroprene.

$$\underset{\text{monovinyl acetylene}}{HC\equiv C-CH=CH_2} + \underset{\text{hydrogen chloride}}{HCl} \longrightarrow \underset{\text{chloroprene}}{H_2C=CCl-CH=CH_2}$$

Several molecules of chloroprene may now be polymerized to form large molecules to produce a plastic material similar to natural rubber in many respects and superior to it in other respects. This product is the new synthetic rubber, neoprene, which will be discussed in Section 9 of this Unit.

Acetylene is also the starting-point for the synthesis of ethylene, acetic acid, acetone, ethyl alcohol, and many other important compounds.

Calcium carbide offers still other interesting possibilities. For example, it will combine with nitrogen to form calcium cyanamide, which may be used directly as a fertilizer or which may be treated with steam to produce ammonia, which is then used to produce ammonium salts for fertilizers. Calcium cyanamide may also be readily converted into urea, which is used in synthetic plastic manufacture, as a stabilizer for explosives, and in other important applications. Calcium cyanamide may also be converted into sodium cyanide, which is used for the extraction of gold by the cyanide process.

Coal May Be Hydrogenated.

Hydrogen may be combined with coal in the presence of a catalyst to produce hydrocarbons for use as fuels or raw materials in the organic chemical industry. The hydrogen may be obtained from water by the action of coke (the carbon left after removing tar from bituminous

coal) with steam. The hydrogenation of coal was used on a large scale by Germany in 1939–1941 to furnish fuels for internal-combustion engines. It is said that Germany spent about $25,000,000 in perfecting the hydrogenation of coal. Their patent royalties in one country alone soon paid back this amount.

STUDY QUESTIONS

1. What is meant by a *synthetic* product?
2. Discuss synthetic dyes as to (*a*) raw materials, (*b*) comparison with natural dyes.
3. Is a natural flavoring product preferable to the same product synthesized in the laboratory? Why or why not?
4. What types of products are obtained from coal tar?
5. How is acetylene obtained from coal?
6. List some of the important substances that can be prepared from acetylene.
7. What important products are obtained in the hydrogenation of coal?

UNIT IX

SECTION 8

THE ALREADY VERY IMPORTANT PETROLEUM AND NATURAL-GAS INDUSTRY IS ABOUT TO ASSUME EVEN FAR GREATER IMPORTANCE AS A SOURCE OF RAW MATERIALS FOR CREATIVE CHEMISTRY

Introduction.

The petroleum industry has come a long way since that day in 1859 when *Colonel Drake* drilled for oil in Titusville, Pennsylvania. The first modern use of petroleum was for the production of kerosene for lamps. Then the development of internal-combustion engines created the demand for motor fuels and lubricants. The increased demand for gasoline brought about many advances in petroleum refining, such as the cracking of gas oil so that the average yield of gasoline from petroleum has been increased from 18 per cent in 1914 to about 44 per cent in 1940. Modern automobiles have made necessary the production of new specialized lubricants and special high-test fuels.

Through research and cooperation the petroleum industry has grown to a point where the social and economic structure of the United States has been built around one of its greatest natural resources, petroleum.

The Petroleum Industry Is the Fifth Largest in the United States.

The United States is the source of 66 per cent of the world's total petroleum production, and three quarters of the world's production is controlled by the Americas. Within its own borders, the United States has petroleum supplies adequate to meet every need, including synthetic rubber and high explosives. The total value of the products manufactured from petroleum in the United States in 1939 was about $2,500,000,000.

In other portions of the world, fuels obtained from the hydrogenation of coal, and gases obtained from coal, wood, lignite, and coke have been insufficient to supplement petroleum fuels for internal-combustion engines. Automobiles, trucks, and buses have been

restricted in their operation, while large containers of coal gas carried on the roofs of vehicles, cylinders of compressed gases, and special carbonizers built onto cars to produce fuel gases by burning wood and other fuels have been introduced.

In 1940 the investments in the petroleum industry amounted to $14,500,000,000. In 1939 the "billion-dollar breathless moment," *i.e.*, the day of the year when the nation's gasoline-tax bill passed the billion-dollar mark, fell on December 15, while in 1940 it arrived on November 15. The petroleum industry has thus helped to build the national wealth through taxes, which, in 1939, totaled more than four times the net earnings of the industry.

The value of the products of the petroleum industry in 1939 was $2,461,126,549, according to the United States Department of Commerce.

The Petroleum Resources of the United States Will Not Soon Be Exhausted.

The crude-oil reserves in known oil fields are about 20,000,000,000 barrels, or sufficient to last sixteen years at the present rate of consumption. Improved methods of oil-well operation, such as gas injection, air injection, acidizing (treating with hydrochloric acid), and flooding with water, have brought about startling increases in oil recovery from old fields in recent years. Modern drilling methods have eliminated the loss due to gushers.

The Petroleum Industry Is the Second Largest in Its Employment of Research.

> Slowly, but surely, the method of Science will help to make life more intelligent, toil more cheerful, fear and hatred and tears less abundant for mankind. — A. J. Carlson.[1]

In 1938 the petroleum industry employed over 5000 research workers, while more than $20,000,000 was spent in petroleum research in 1939. Through research, refining processes have become more efficient. Only about half as much fuel is consumed today as was consumed in 1925 in the refining of a barrel of oil, while twice the amount of gasoline refined for a given investment in 1925 is now produced for the same investment.

Production operations have also been made more efficient. Under older methods only about 20 per cent of the oil present in producing formations could be brought to the surface, while modern methods have nearly tripled this yield.

[1] *Science News Letter*, January 11, 1941, p. 29.

Research has decreased the cost of gasoline. The average service-station price of gasoline in 1920, minus taxes, was 29.7 cents per gallon, while it had been reduced to 13.4 cents per gallon by 1939.

Modern Petroleum-prospecting Is Scientific.

During the 17 years starting with 1922, 1183 new oil fields were discovered, 796 of which were major pools estimated at more than 1,000,000 barrels of recoverable oil each. Of these 796 major pools, 746 were discovered by geological and geophysical methods, thus leaving only 50 pools to the credit of random drilling or "wildcatting." The newer tools of geophysics include seismography, the torsion balance, the gravitometer, the magnetometer, and the electric log.

Geochemical methods, by which samples of soil are analyzed for waxes, oil, and hydrocarbon gases and which are so sensitive that a few parts of ethane per billion may be determined, are now coming into vogue.

The mass-spectrograph of the physics laboratory is the modern geochemical divining rod. Analyses may be made on samples of gases smaller in volume than the head of a pin, and the results may be obtained within ten minutes.

Seismographic exploration uses sound waves from test explosions sent down through one stratum after another and recorded as they bounce back. From these data underground configurations are plotted and the possibility of oil-bearing structures determined.

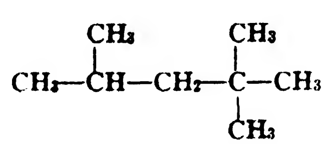
Another modern device is an electric eye which is very sensitive to gamma rays. It is lowered into a well, where it responds to varying emissions of gamma rays from different strata, thus helping to identify them.

Twenty years ago wells cost about $10,000 each and went down only 2000 to 3000 feet. Now wells may cost $150,000 or more and frequently are drilled to a depth of from 8000 to 15,000 feet.

Many Improvements Have Been Made in the Manufacture of Motor Fuels and Lubricants.

About half of the gasoline produced today comes from the cracking of petroleum. This gasoline possesses antiknock properties, so that the octane number[1] of the average gasoline not treated with tetra-

[1] Octane number — In the standard method for rating the antiknock value of gasoline, iso-octane,



is arbitrarily assigned the value of 100, while normal heptane, CH_3—CH_2—CH_2—CH_2—CH_2—CH_2—CH_3, is given the value of 0. The percentage of iso-octane that has to be mixed with heptane to reduce the intensity of the knocking of the mixture to that of the gasoline is called the antiknock rating or, preferably, the *octane number*.

ethyl lead was about 50 in 1916, while today unleaded gasolines with octane numbers as high as 80 are being marketed.

One of the newer developments in petroleum technology is to treat straight-run gasoline in a hydro-forming plant to improve its octane rating. This process is halfway between hydrogenation and catalytic cracking.

The cracking processes previously referred to have been used for many years to convert heavy petroleum products into gasoline by thermal treatment at temperatures in the range of 900–1100° F. at pressures usually above 100 pounds and frequently as high as 1000 pounds. Catalytic cracking processes have only recently been in commercial use. These processes produce gasolines of higher antiknock value and have other commercial advantages. One such process is that developed by *Eugene Houdry*, which uses an alumina-silica catalyst at a temperature of around 900° F. and a pressure slightly above atmospheric. The gasolines produced have an octane number of around 80, compared with 70 octane number for thermally cracked gasolines, and are low in gum and sulfur content. Catalytic cracking processes usually give higher total liquid yields than do thermal cracking processes.

In 1941 another cracking process, known as the fluid catalyst process, promised still greater economy in production costs and higher yields.

The gasoline content of crude oil varies widely with the origin of the crude, but the average is about 30 per cent or less. If it were not for the development of cracking processes, we would have consumed more than twice as much crude oil, and there is no way of telling what the price would have been today. Undoubtedly the research work which led to the cracking processes has been the most constructive conservation project up to the present time, because it has not only given us more than twice as much gasoline from a given amount of crude oil, but it has also practically doubled the efficiency of automobile engines because of the higher compression ratio which the higher octane number of cracked gasoline made possible.

Tetraethyl lead used in gasoline in quantities of less than 0.1 per cent to improve the antiknock properties exceeds in dollar sales that of any other synthetic organic chemical with the possible exception of ethyl alcohol.

Antioxidants, such as various substituted aminophenols, employed in concentrations of less than 0.01 per cent, stabilize gasoline against gum formation and deterioration during storage.

Various kinds of synthetic organic chemicals, such as alkyl and aryl

phosphates and phosphites, and metallic soaps, are added to oils to improve their lubricating properties.

New fuels of the order of 100 octane number are obtained by treating butane and butylenes produced in large quantities from cracking operations. For example, isobutylene may be polymerized with sulfuric acid or a solid catalyst and the resulting compound hydrogenated to produce branched octanes of high antiknock value. Copolymers of the lower olefins are also produced in large quantities. In 1940, about 1,600,000 gallons of such polymer gasolines were made daily in the United States, of which some 600,000 gallons had in the neighborhood of 97 clear octane number, making them suitable for the manufacture of high-grade aviation fuel.

An even more recent development is alkylation, which consists of reacting a lower isoparaffin — *e.g.*, isobutane — with lower olefins — *e.g.*, butylenes — in the presence of strong sulfuric acid to give just about the theoretical amount of combination product with an octane number in the range of 92–96 and a preponderance of material boiling in the aviation-fuel range.

The newer airplanes in the United States, with engines having a compression ratio of eleven to one designed for 100 octane fuel, can lift 25 per cent more dead weight and gain 25 per cent more translational speed than airplanes with engines designed to use 87 octane fuel.

Miles per gallon of gasoline for automobiles have not increased as much as one would expect during the past few years because the public has demanded higher and higher performance, *i.e.*, more power to provide greater accelerating capacity and hill-climbing ability. Performance has been greatly increased during the past few years without any loss of miles per gallon of gasoline as the result of the use of gasolines of higher octane numbers and better volatility. Performance has been boosted since 1927 by an average of about 45 per cent, while the economy of operation has increased by almost 20 per cent.

The next step in the improvement of the automobile will undoubtedly be that of higher fuel economy made possible by an increase in octane number. Experimental data show that an increase in octane number from 70 to 100 would make possible automobile engines with higher compression ratios that should result in a gain of about 28 per cent in both economy and performance at 60 miles per hour. In general an altogether knock-free fuel would make it possible either to double the mileage or to double the power, but not both at once. The use of higher octane fuels even if they are sold at higher prices would cost less than the use of present fuels, and at the same time a considerable conservation of our fuel resources would be made possible.

Large-scale production of 100 octane motor fuels may make it possible to produce smaller engines, which can be placed in the back end of automobiles, thus revolutionizing their design.

Superior lubricating oils are also being produced by the polymerization of refinery gas products.

Although the fractions boiling in the gasoline range may consist of literally hundreds of hydrocarbons, so much progress has been made in distillation and solvent extraction that it now is possible to prepare less complex mixtures and even some very pure compounds.

The petroleum industry is now looking forward to the time when petroleum will be used as a source of raw materials from which relatively pure hydrocarbons may be prepared by synthetic processes.

> We are so breathless with the progress already made that few of us are able to see where this road along which we have moved so rapidly over the last few years will lead us. Apparently it is leading us in the direction of converting the natural hydrocarbons of petroleum into simpler compounds of less molecular weight, and then recombining these simpler compounds in new ways to obtain an entirely new molecule having the characteristic that we want, and which we cannot obtain in the natural molecule.[1]

There Is a Great Future for the Use of Petroleum as the Starting-point for the Preparation of Many Valuable Products.

Ethylene, C_2H_4, which is obtained in large quantities by cracking petroleum, is now combined with bromine, obtained from sea water, to produce ethylene dibromide, $C_2H_4Br_2$, which is added in small amount to tetraethyl lead in "ethyl" gasoline to form lead compounds which pass out through the exhaust, thus preventing accumulation of lead in the combustion chamber. Ethylene also combines directly with chlorine to produce ethylene dichloride, $C_2H_4Cl_2$, which is useful as a fat solvent and is also added to "ethyl" gasoline with ethylene dibromide. It will react with water to produce ethylene glycol,[2] $C_2H_4(OH)_2$, which is used in automobile radiators as an antifreeze. Glycol is converted into other substances such as "cellosolve" and "carbitol," which are used as solvents, and glycol dinitrate, which is used in low-freezing dynamite.

A method for the preparation of toluene, $C_6H_5CH_3$, from petroleum has made the United States independent in regard to this raw material from which T.N.T. (trinitrotoluene), the high explosive, is manufactured.

It is now possible to produce from petroleum the important aromatic compounds which were formerly obtained only from the destruc-

[1] F. A. Howard, *Chemical Metallurgy Engineering*, Vol. 46, No. 751, 1939.

[2] Most of the glycol made in the United States is produced by a different process.

tive distillation of coal; for example, benzene, toluene, xylenes, alkyl naphthalenes, and high-solvency naphthas high in aromatics.

Cresylic acid (a mixture of phenols), formerly obtained from coal tar alone, is now obtained from petroleum at a lower cost. It is used for the preparation of germicides and insecticides and on a large scale in flotation processes for the recovery of ore particles from crushed rock.

In the process of cracking large molecules to form molecules suitable for gasoline, the production of smaller fragments, which are too volatile to be used in gasoline, is unavoidable. Between 7 and 8 per cent by weight of the total crude oil processed in our refineries becomes gas. This amounts to about 14,000,000 tons per year. One company alone was making over one hundred synthetic chemicals from these refinery gases in 1940.

Propane and butane, refinery gases formerly burned as fuels in the refinery boilers, are now liquefied and sold as "bottled gas" for use where neither natural gas nor manufactured gas is available and even in trucks and buses; 128,000,000 gallons of "bottled gas" were sold in 1939.

One interesting use for propane is the removal of wax, asphalts, and resins from lubricating-oil stocks. Dewaxing is effected by dissolving the oil in liquefied propane, evaporating a portion of the propane and thus chilling the mixture, and subsequently filtering or settling the wax crystals so formed. Residual stocks are deasphalted by partial solution in liquefied propane. Furthermore, by proper selection of the concentration and temperature, the very heavy portions of the oil, nonasphaltic but "resinous," may be separated from the balance of the oil. Thus deasphalting and deresinating are in effect a substitute for high-vacuum distillation. Olefinic and other easily oxidized constituents of lubricating oils, as well as materials having poor viscosity-temperature characteristics, are separated from lubricating oils by solvent extraction. Examples of selective solvents are sulfur dioxide, chlorex, furfural, and phenol. The result of the combination of these processes is the production of extremely high-quality motor oils with excellent viscosity-temperature coefficients, high stability, and low pour-point.

Already refinery gases (former waste products) are being used to produce ethylene glycol (antifreeze), glycerine, acetone, and ethyl alcohol. Instead of using alcohol derived from the fermentation of carbohydrates to replace gasoline as a fuel, as has been done in other countries, we have seen petroleum used to produce cheaper and purer alcohol to compete with fermentation alcohol in all of its many applications.

In addition to ethyl alcohol, isopropyl, isobutyl, and secondary butyl alcohols are obtained in large quantities from refinery gases. Large quantities of isopropyl alcohol are now being used as antifreeze for automobiles. These alcohols are not only important products themselves, but they are still more valuable because of the ethers, esters, and similar compounds of many uses which may be prepared from them.

Soaps and fats are now being made from petroleum-like substances obtained by the catalytic hydrogenation of water gas in Germany, and plastics and synthetic rubber are now being prepared from petroleum in the United States.

Naphthenic acids obtained from petroleum are used to manufacture paint-driers, waterproof compounds, disinfecting soaps, wood treatments to prevent barnacles, termites, rot, etc., adhesives, flotation oils, wetting agents, plasticizing agents, leather tanning, etc.

The Practice of the Petroleum Industry in Its Use of Patents Is a Good Example of Cooperation in Action.

The petroleum industry has not been secretive about its technical developments. The major companies have freely published and exchanged the knowledge gained in their research laboratories, largely because of their reliance on our patent system to protect them. If this protection should break down, research would then take place behind closed doors, and its usefulness to the public would decrease.

> The almost uniform practice of the oil companies has been to settle conflicts amicably by cross-licensing and providing that the patent claims of both interferents can be made available to third parties upon reasonable terms. Having settled, between themselves, any differences as to their respective rights to use the process the two contracting parties can and frequently do exchange unpatented technical data pertinent to its operation. No important process has been developed in recent years by any company or group of companies which has not been offered freely to competing companies at a royalty which represented only a small fraction of the savings to be obtained by its use and without restrictions as to the price at which the resultant product shall be sold.[1]

Natural Gas Is an Important Natural Resource.

Ninety-eight per cent of the world's supply of natural gas is concentrated in the United States. An insignificant amount of this natural gas could furnish all of the explosives that we could use in peace or war times. *Professor Henry B. Hass* has developed processes by which nibglycerol trinitrate, a high explosive, much safer than the

[1] Bruce K. Brown, Standard Oil Co. (Indiana), *News Edition*, American Chemical Society, April 25, 1940, pp. 353–354.

powerful nitroglycerine, may be made by treating natural gas with nitric acid to produce nitroparaffins and then condensing these products with formaldehyde and nitrating the condensation product. Glycerine may also be prepared using this basic process.

Glycerine may be prepared from propylene, a gaseous product of cracked petroleum, by the action of chlorine and sodium hydroxide. By combining glycerol with acids, an unbelievable array of valuable edible oils and fats may be prepared.

A new alcohol, made from refinery gas or natural gas, increases the wetting ability of water by lowering its surface tension. Water to which a little of this alcohol has been added makes a better spreader for insecticides and lays dust better than ordinary water.

Ethylene is obtained in large quantities from the gases produced during the cracking of petroleum oils, but it is in such demand that additional very large quantities are produced by the pyrolysis (destructive heating) of natural gas.

The unsaturation of ethylene enables it to be combined in good yield with various reagents, such as water, hydrochloric acid, chlorine, and hypochlorous acid. From these derivatives an almost unlimited number of compounds may be obtained. The Carbide and Carbon Chemicals Corporation has made an outstanding achievement in the production of chemicals from petroleum and natural gas.

More than one hundred commercial chemicals, such as alcohols, ketones, esters, and amines, are being manufactured from the products of cracking natural gas. Today over fifty million pounds of glycols are made from natural gas annually, although not a pound was produced in 1929.

In one large nitrogen-fixation plant in California, the hydrogen for this process is obtained by cracking natural gas, the carbon which is formed as a by-product being compressed into briquets for use as a fuel.

STUDY QUESTIONS

1. Discuss briefly the influence of the petroleum industry on the social and economic structure of the United States, comparing the United States with nations lacking adequate petroleum resources.
2. In what respects have the petroleum cracking processes conserved our petroleum resources?
3. Is there any possibility that our petroleum resources will be exhausted within our generation?
4. Is it true that petroleum is an irreplaceable resource?
5. How has the octane number of gasoline been improved by the petroleum industry?

6. What are the advantages of a high-octane gasoline for automobiles and airplanes?
7. How do you account for the rapid advances which have been made in petroleum technology?
8. Why is one justified in saying that "the petroleum industry is about to assume far greater importance as a source of raw materials for creative chemistry"?
9. List some of the important materials that are now being created from refinery gases.
10. How is 100 octane gasoline obtained from petroleum refinery gases?
11. What is meant by (*a*) cracking, (*b*) polymerization, (*c*) hydrogenation, (*d*) hydroforming? Illustrate by examples taken from petroleum technology.
12. What is the present goal of the petroleum refining industry in its treatment of crude petroleum?
13. Why is the petroleum industry not satisfied with its present petroleum products such as gasoline and lubricating oil?
14. Compare modern oil-prospecting with the "wildcatting" of earlier days.
15. Show how petroleum might well be the starting point for edible fats and oils.
16. Compare modern oil-drilling with that of earlier days.

UNIT IX

SECTION 9

NATURAL AND SYNTHETIC RUBBERS ARE VERY IMPORTANT INDUSTRIAL MATERIALS

Introduction.

Rubber is obtained by coagulating the latex obtained by tapping rubber trees. Originally the best grades of rubber were prepared from latex obtained from wild rubber trees (*Hevea braziliensis*) in the Amazon region of Brazil. Other grades were obtained from Landolphia and Funtumia plants in Africa and from the Castilloa tree of Central America. In 1876 *Sir Henry Wickham* smuggled 70,000 seeds obtained from the best rubber trees along the Rio Tapajoz, which furnished the start for the cultivated rubber plantations in the East Indies. The production of plantation rubber rose from 11,000 tons in 1910 to nearly a million tons in 1940, while the production of wild rubber decreased from 54,000 tons in 1900 to about 10,000 tons in 1940. High prices maintained by a combination of British and Dutch planters caused the United States Rubber Company and the Goodyear Tire and Rubber Company to establish plantations in the Far East. Later *Harvey Firestone* started plantations in Liberia, while *Henry Ford*, after ten years of costly research, developed a large plantation in Brazil.

The Discovery of Vulcanization Enabled Man to Put Rubber to Work.

The desirable properties of natural rubber were early recognized, but products made from it had the disadvantage that they became soft and sticky when warmed and also became very stiff at winter temperatures. In 1839 *Charles Goodyear* discovered that hardness and resistance to deterioration could be imparted to rubber by mixing sulfur with it and heating the mixture. This process, called *vulcanization*, was but the beginning of a long series of researches which have resulted in the improvement of natural rubber for many purposes from year to year.

The long, chainlike molecules of rubber are responsible for its extensibility, while the pronounced unsaturation of these molecules

makes it possible, according to the most accepted modern theories, to link one molecule to another using sulfur as the bonding agent, thus producing tough, strong, and even very hard products, depending upon the amounts of sulfur used.

> When the storms of Charles Goodyear's failures gave way in 1839 to the sunshine of success, he found at the end of his rainbow, not a pot of gold, but a strip of vulcanized rubber that was the forerunner of to-day's billion-dollar rubber industry.
>
> The discovery was one of those "accidents" that come to those who strive to observe. It happened when the difficulties of the experiment, financial worries, and even ill-health were at their worst. Ironically enough, Goodyear's success resulted from a condition previously considered a hindrance — heat.
>
> Thoroughly familiar — to his financial loss and chagrin — with the effect of heat on rubber, Goodyear was defeated time after time in his effort to find how rubber could be made heat-resistant. That he was ultimately successful is a tribute to his perseverance, his thoroughly scientific mind, his resourcefulness, and his keen powers of observation.[1]

Of Goodyear's accidental discovery that rubber could be made heat-resistant by heating it with sulfur, Goodyear said:

> That which is hidden and unknown and has not been revealed by direct methods will most likely be discovered by an accident, by the man who applies himself perseveringly to the subject and is most observing of everything related thereto.

In 1844 Goodyear was granted a patent for his discovery, which was often and bitterly contested. He was represented in one legal battle by the eloquent *Daniel Webster*, who said in the course of the trial, "This discovery will work important changes. It introduces a new material into manufacture, nothing less than elastic metal."

The rubber industry is very important today. One American manufacturer advertises over thirty-two thousand different items made from rubber, while several hundred thousand patents dealing with rubber have been granted.

Some of the more important newer developments in the utilization of rubber are:

1. The Electrodeposition of Rubber. The particles of a rubber emulsion have a negative charge and may be attracted to a positive electrode, which may be in the form of a human hand made of metal on which true-fitting rubber gloves are thus deposited. Or, a metal plate may be covered with a textile fabric in which the rubber is deposited to make a waterproof material containing very little rubber.

[1] *The Laboratory*, Fisher Scientific Company, Vol. X, No. 5.

2. Sponge Rubber. Sponge rubber made by vulcanization of foamed-latex compositions is now used for mattresses and upholstering furniture and automobile seats.

3. Chlorinated Rubber. Chlorine will combine with rubber to form tough and horny resins which contain about 65 per cent chlorine. These resins are very resistant to water, acids, bases, salts, and many organic solvents and are finding wide application in the preparation of corrosion-resistant paints, lacquers, and floor coverings and in flameproofing textiles. "Paratex," "Parlon," and "Tornesite" are typical chlorinated rubber products.

4. Rubber Hydrochloride. Hydrogen chloride combines with rubber to form a moisture-resistant, flexible, shock-resisting material of many uses. Under the name of "Pliofilm" it is now found in shower curtains, raincoats, and protective covers for foods and other merchandise, wherever low moisture and oxygen permeability, together with a high degree of flexibility and toughness, are desired.

5. Pliolite. "Pliolite" is a resin prepared by the cyclization of rubber with stannic chloride or other similar compounds as catalysts. It finds useful applications in the paint, lacquer, and moistureproofing industry.

6. Rubber-metal Bonding Cement. Sulfonic acid or sulfonyl chlorides react with rubber to form isomers of a lower degree of unsaturation than rubber. Certain of these have been found to bond rubber firmly to metal. A solution of the isomer is applied to the clean metal surface, and the rubber is vulcanized in contact with it. This process is known as the "Vulcalock" process. This is one method by which tank cars, stationary tanks, and pipe are lined with rubber.

7. Kolok Fabrics. "Kolok" is the name of a fabric in which minute particles of latex have been deposited in such a way as to bind the fibers together. These fabrics are said to wear twice as long, fit better, appear neater, and resist shrinkage better than untreated fabrics. Millions of pairs of silk hosiery have been given the Kolok treatment.

Some of the newer developments in the use of rubber are airplane armor plate of laminated rubber and steel, self-sealing (and therefore bulletproof) fuel tanks for airplanes, rubber printing plates which save 25 per cent on ink and a considerable amount of time in printing. The time saved through the use of rubber printing plates is in the so-called "make ready." When printing from metal type, all parts of the surface have to be carefully adjusted so that in printing none of the type causes depressions in the paper. Because of its flexibility, rubber will not cause depressions in the paper and "make ready" time is greatly reduced.

In 1895 the *Michelin* brothers entered a car equipped with pneumatic tires in the Paris-Bordeaux race. The course was 732 miles long, and 22 inner tubes were used up in the race. By the use of appropriate accelerators, antioxidants, and reinforcing agents, chemists have been able to produce stronger and better-wearing rubber compounds, so that every year has seen an improvement in automobile tires. Fifteen years ago no tire manufacturer would have thought of guaranteeing a tire to last twenty-five to fifty thousand miles, and

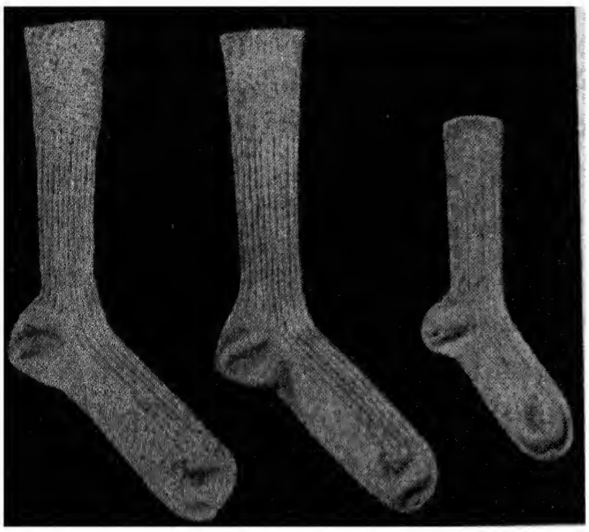


Fig. 303. Fabrics treated with "Kolok" not only wear longer but also resist shrinking and repel moths. The process consists in depositing within the fabric minute particles of latex solids. Left, control. Center, "Kolok" treated sock after washing. Right, untreated sock after washing. (Courtesy of the United States Rubber Company.)

yet it is a frequent occurrence for modern tires to last more than a hundred thousand miles when used under optimum conditions.

In the manufacture of commercial rubber products, in addition to the sulfur added for vulcanization, there are used reinforcing pigments such as charcoal black for black rubber, zinc oxide for white rubber, fillers, and organic compounds which will accelerate the rate of vulcanization and thus speed up production. Other organic compounds are added to reduce the rate of the action of light and oxygen on rubber products.

Comparison of Vulcanization

	Without Accelerator	With 0.08 Per Cent Accelerator
Time of vulcanization of a small tire	200 or more minutes	Approximately 50 minutes
Tensile strength of pure gum compounds . .	1150 pounds per square inch	2300 pounds per square inch

The development of colloidal carbon black, which constitutes up to 33 per cent of the components of tire treads, made possible the mod-

ern carbon-black rubber compounds which have increased the length of life of tires from about three to about twenty thousand miles. Through research the cost of colloidal carbon black has been brought down from eight cents to three or four cents per pound.

Natural Rubber May Be Replaced Advantageously by Synthetic Products for Many Purposes.[1]

Natural rubber is used in automobile tires because of its resistance to repeated flexure, its low energy absorption, the high abrasion resistance of tread compounds, and the low permeability of air through rubber (inner tubes). In the electrical industry it is the electrical insulating property of rubber that is important, while its ability to shed water is utilized in waterproofing raincoats. In the preparation of synthetic substitutes for rubber, the original idea was to prepare a synthetic rubber having the composition and properties of natural rubber.

An analysis of natural rubber showed that it is a hydrocarbon of the general formula $(C_5H_8)n$. It was concluded, therefore, that a synthetic rubber could be obtained by the polymerization of isoprene, C_5H_8, $CH_2{=}CH{-}\overset{\overset{\displaystyle CH_3}{|}}{C}{=}CH_2$. It was found that isoprene could be obtained from the turpentine obtained from pine trees, but this was too expensive a source of isoprene.

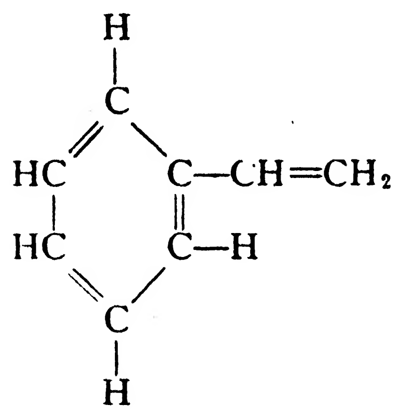
In connection with the isoprene research it was discovered that another hydrocarbon, butadiene, $CH_2{=}CH{-}CH{=}CH_2$, could be polymerized in the presence of sodium to produce a rubber-like compound. Buna rubber ("Bu" from butadiene and "Na" from sodium) was developed in Germany in the late twenties from acetylene, which, in turn, was prepared by the action of water on calcium carbide (a product obtained from coal and limestone). There are several types of Buna rubber. The oil-resistant variety was known as Buna N or Perbunan. Buna S is not oil-resistant.

The improvement of natural rubber by treatment with other substances and the discovery that Buna rubber was more resistant to organic solvents than is natural rubber led to the idea that it might be possible to prepare new synthetic products, differing in composition from natural rubber, which would be superior to natural rubber for various purposes. It was realized that erasers and automobile tires do not need to be electrical insulators and that hard-rubber articles

[1] For a comprehensive review of synthetic rubbers, see: Lawrence Wood, "Synthetic Rubbers, A Review of Their Compositions, Properties, and Uses," *Circular* of the National Bureau of Standards, C 427, Government Printing Office, Washington, 1940.

need not be extensible. Natural rubber suffers from several disadvantages. It swells on contact with organic liquids such as petroleum products (gasoline, lubricating oils, etc.); it is not resistant to oxidation by the oxygen of the air.

The original synthetic rubber, a polymer of dimethylbutadiene, developed by Germany during World War I, was a poor substitute for natural rubber, but it has been greatly improved by building large molecules from a mixture of butadiene and other unsaturated compounds. Thus Buna S tires on which the German mechanized army rode in 1940–1941 were made by polymerizing butadiene with styrene.



This rubber is approximately equal to natural rubber in its resistance to abrasion and heat.

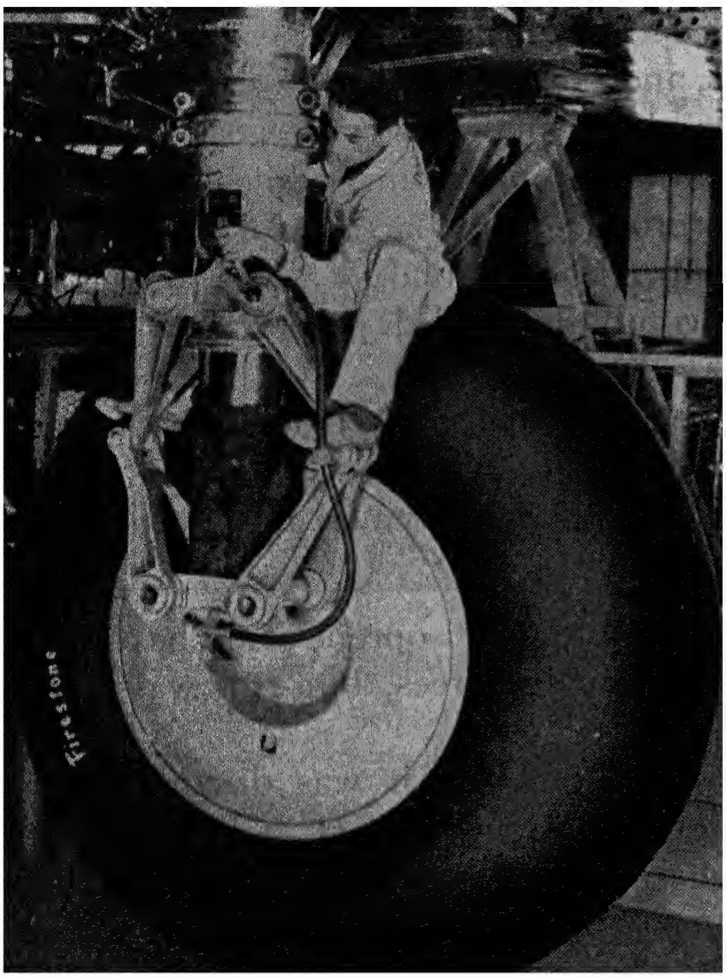


FIG. 304. The Firestone B-19 bomber tire. (Courtesy of the Firestone Tire and Rubber Company.)

Buna N, more commonly referred to as Perbunan, is another copolymer of butadiene, which is particularly desirable because of its resistance to swelling with liquid hydrocarbons. Buna N is made by polymerizing butadiene with acrylonitrile, $CH_2{=}CH{-}C{\equiv}N$. Tires made from Perbunan may wear slightly longer than tires made from natural rubber. In 1940 the Standard Oil Company, a corporation of New Jersey, made public its plans to erect a Buna plant having a capacity of 10,000 pounds per day under the patent rights originating with German chemists and now owned by one of Standard's United States subsidiaries. This plant went into operation in 1941 at the refinery of the Standard Oil Company of Louisiana in Baton Rouge.

In 1941 the United States Government arranged with four rubber companies to build synthetic rubber plants each with an initial capacity of 2500 tons per year, to be increased eventually to 10,000 tons per year for each plant.

About 1930 the E. I. du Pont de Nemours Company produced a new synthetic rubber, neoprene, from the basic materials, coal, limestone, and salt. Acetylene prepared from calcium carbide was changed in the presence of catalysts (cuprous salts) to monovinyl acetylene, $HC{\equiv}C{-}CH{=}CH_2$, which was heated with hydrochloric acid, HCl, made from salt to produce chloroprene, $H_2C{=}\underset{}{\overset{\displaystyle CL\atop|}{C}}{-}CH{=}CH_2$. Chloroprene is polymerized to produce neoprene. Neoprene is superior to natural rubber in its resistance to hydrocarbon solvents, to light, and to oxidation. Unlike natural rubber it does not require sulfur for vulcanization.

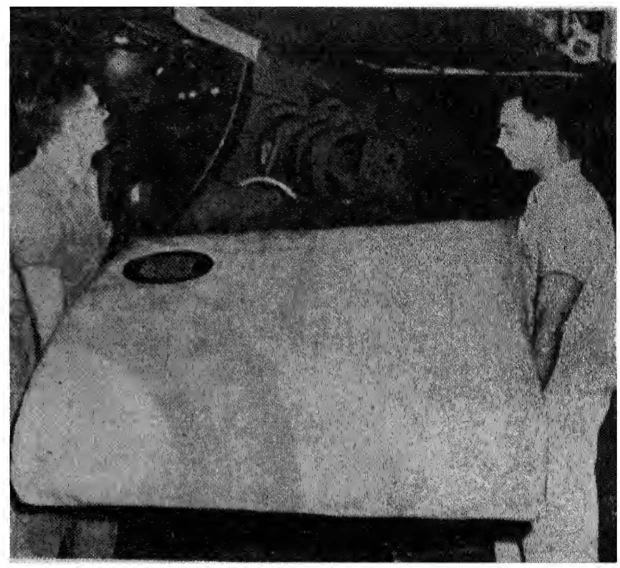


FIG. 305. A self-sealing rubber airplane tank. (Courtesy of the United States Rubber Company.)

Neoprene is used to advantage in the manufacture of hose for any purpose where oil or other hydrocarbons are likely to be present, for conveyor belts, packing, printing rollers, electrical cables, ignition wire, gloves, protective clothing, motor mountings, nonslip floor wax, and many other products which are subjected to conditions that quickly deteriorate natural rubber. The Russians make a synthetic rubber known as Sovprene, which is believed by some people to be similar to neoprene. Sovprene is the name given to the Russian version of neoprene. In late 1941 the production of neoprene had been raised to 1,500,000 pounds per month, and a new plant was being erected by the E. I. du Pont de Nemours and Company at Louisville, Kentucky, which is to have a capacity of around 20,000,000 pounds per year.

Another solvent-resisting rubber substitute which was developed at about the same time that neoprene was developed is made from ethylene dichloride and sodium tetrasulfide. The ethylene is obtained from petroleum refinery gases, and the chlorine and sodium tetrasulfide come from salt and sulfur. This rubber substitute is called "Thiokol." It was discovered by *J. C. Patrick* in 1920 in connection with a research for a cheaper antifreeze solution. In 1938 the consumption of "Thiokol" exceeded one million pounds.

Another new rubber substitute which, like "Thiokol," is unrelated to rubber, is "Koroseal." "Koroseal" is a polymer of vinyl chloride,

$$-CH_2-\overset{\overset{\displaystyle Cl}{|}}{C}H-CH_2-\overset{\overset{\displaystyle Cl}{|}}{C}H-CH_2-\overset{\overset{\displaystyle Cl}{|}}{C}H-,$$

which, like neoprene, has its origin in acetylene or natural gas and salt. It finds application where absolvent- and corrosion-resistant product can be used to advantage.

"Koroseal" compositions vary from materials similar to hard rubber to stiff jellies. They are used to line metal tanks, to make gaskets, to

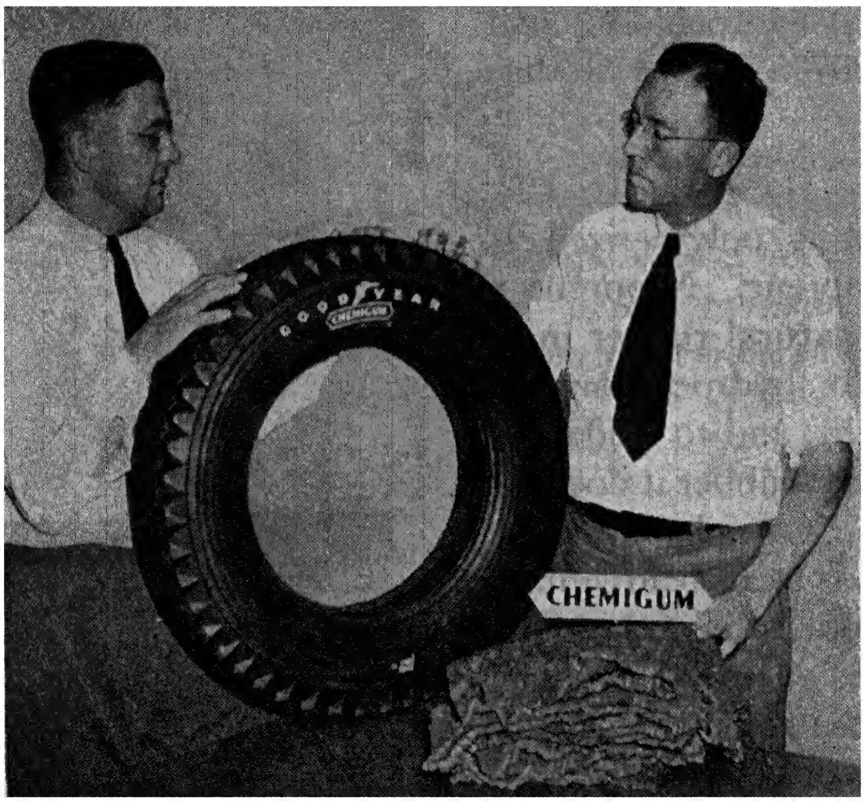


FIG. 306. A "Chemigum" tire, the raw material for which is essentially butadiene, to which is added other materials such as acrylonitrile or styrene. "Chemigum" products are oil and gasoline resistant. (Courtesy of the Goodyear Tire and Rubber Company.)

coat papers, to insulate electrical conductors or cables, to join textile fabrics by heating with a warm iron, and to prepare acid-resistant paints under the name of "Koroplate." "Koroplate" is also oil-resistant, and for that reason it is used to coat the inside of oil-storage tanks. "Koroseal" is made in a variety of beautiful colors. "Koroseal"-treated cloth has been used for clothing, shower curtains, and umbrellas. "Koroseal" has also been used extensively for wrist-watch straps, suspenders, garters, and trouser belts. A special composition containing aluminum is marketed in the form of ironing-board covers which enable the user to iron more pieces in a given time.

Three new polymers which possess properties which should make them competitors of natural rubber for the manufacture of automobile

tires are Butyl rubber, "Chemigum," and "Hycar," all of which have their origin in petroleum. Butyl rubber is a copolymer of olefins with diolefins, which are obtained from petroleum refinery gases. By varying the composition of the raw materials, the properties of the synthetic rubber may be controlled to meet various specific needs. "Hycar" rubber is used in the manufacture of "Ameripol" tires.

Butyl rubber is colorless, odorless, tasteless, and more stretchable than natural rubber.

> Rubber molecules are extremely polygamous, for even after being married in the vulcanizing process, they still want to join others. They will combine with oxygen from the air, for example, and this causes deterioration of rubber with aging even though it is not in use. The chemist calls this willingness of the molecules to marry others "unsaturation." The butyl rubber molecules have just enough saturation to permit them to combine with sulphur for strength. Then they are satisfied, and do not tend to react further.[1]

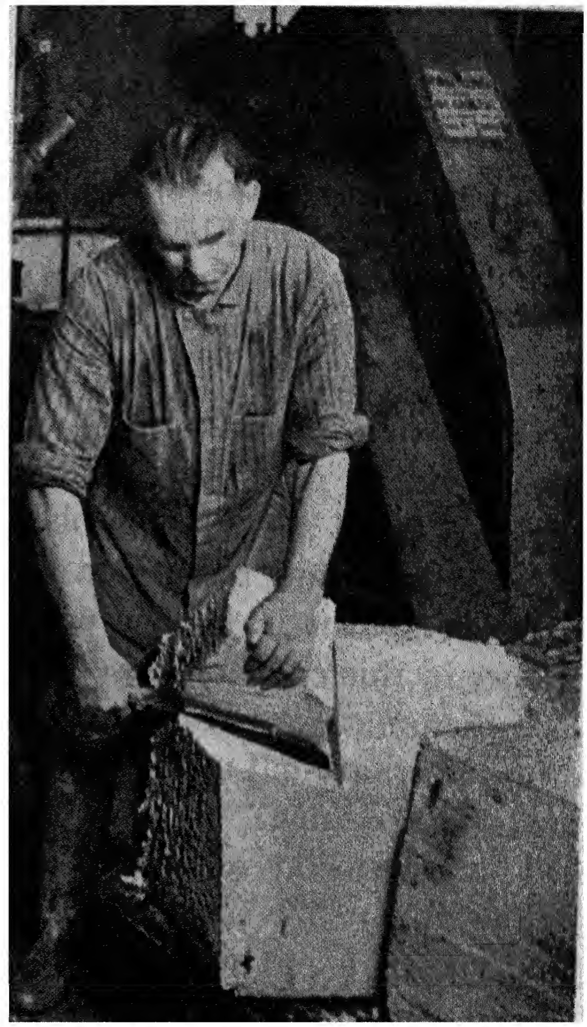


FIG. 307. Cutting a block of raw Ameripol synthetic rubber. (Courtesy of B. F. Goodrich Company.)

Because these synthetic butyl rubber molecules, after vulcanization, are saturated, they possess a remarkable stability and durability.

The consumption of crude rubber in the United States is about 1,350,000,000 pounds per year, 97 per cent of which comes from the Far East. In 1940 the production of all types of synthetic rubber was only 50,000 pounds per day, or less than 2 per cent of the crude-rubber imports, so it is quite evident that there is room for a great expansion of the synthetic-rubber industry. The erection of the necessary plants to produce enough synthetic rubber to replace a substantial portion of the natural rubber now used would require a number of years. The degree to which non-oil-resistant varieties of synthetic rubber will replace natural rubber depends upon their relative prices. Synthetic rubber has been sold at a price as low as 65 cents per pound, while the

[1] *Science News Letter*, September 21, 1940, p. 179.

price of natural rubber has fluctuated from 3 cents to $1.35 per pound within the past twenty years. Plantations can make an excellent profit when natural rubber sells at between 15 and 18 cents per pound provided that shipping costs are normal. The manufacture of synthetic rubber is likely to help to stabilize the price of natural rubber.

All the forms of synthetic rubber could be produced from petroleum as the main raw material, and if our total supply of rubber were produced from petroleum it would use only one third of one per cent of the annual production of crude oil. To a large extent the petroleum products used would be by-products, such as refinery gases, for which there has been little sale up to the present time.

The possible production of natural rubber prior to "Pearl Harbor" was 1,600,000 tons per year, while the normal consumption was only 1,000,000 tons. This surplus of natural rubber would have increased as additional plantations came into production. Natural rubber is superior to all synthetic rubbers in regard to elasticity and rebound, extensibility, and resistance to stiffening at low temperatures. The types of synthetic rubber now available would not displace natural rubber in this country, except for specialized purposes, for a long time to come unless wars made it impossible to ship the natural rubber or other international upheavals make it impossible to obtain the rubber for other reasons.

The expansion of the synthetic-rubber industry would probably follow the usual pattern unless emergency conditions change this pattern. This pattern is about as follows:

1. The introduction of a product of exceptional quality at higher prices than the products which it will replace.
2. The gradual lowering in the price and improvement in the quality as increased production and additional experience and research iron out production wrinkles.
3. New applications made possible by lowered costs and increased quality again increase production and again decrease the price until it is competitive with the price of the product which it is displacing.
4. Competition results in more research, still lower prices, and improved quality, with the result that the consumer can buy more "better things for better living."

STUDY QUESTIONS

1. How do you account for Goodyear's "lucky accident"?
2. What is meant by "vulcanization of rubber"?
3. Describe some of the important new developments in the utilization of rubber.
4. Why do the automobile tires of today give much better mileage than the tires of ten or twenty years ago?

5. What are the functions and advantages of the accelerators and the antioxidants used in rubber compounding?
6. Discuss the various types of synthetic rubber as to (*a*) the raw materials from which they are made, (*b*) their properties, and (*c*) their uses.
7. Why are some types of synthetic rubber more resistant to chemicals, solvents, heat, and light than is natural rubber?
8. What is the usual pattern for the development of synthetic chemical industries?

United States alone amounts to more than $1,500,000,000. The Federal Government appropriated somewhat more than $2,182,532 for the fiscal year 1941 for research work for the Bureau of Entomology. More than $200,000,000 is spent each year in the United States for insecticides and fumigants.

Armies of insect allies have been drafted to combat insect enemies. For example, a gnat-sized wasplet has helped a great deal in abating the ravages of the codling moth. Space will not permit the discussion of many other examples where beneficial insects are used to control injurious insects. The immediate onslaughts of enemy insects must usually be met by chemicals of various kinds, the nature of which is determined by the insects being combated.

The majority of insects are harmless, and many of them are of definite economic importance.

Insects Are Man's Chief Competitors for Foods.

In the grim struggle between man and insects, the latter possess the advantage of small size, which enables them to live on small quantities of food and multiply enormously when plenty of food is available. A large oak tree may support as many as one million insects, while forest loam may contain as many as fifty million insects per acre.

Insects also possess the advantage of rapid reproduction in large numbers. For example, a single pair of ladybird beetles could multiply to 22,000,000,000,000 beetles in six months if conditions were favorable. The progeny of a single pair of aphids, if they all lived, would be sufficient at the end of one year to fill up the Atlantic Ocean. The warfare against insects is never finished because new legions can replace their fallen brothers and sisters in a short time.

Insects are superior to man in that they carry lighter weights and do their work with a smaller expenditure of energy than is possible for man. There are insects which can live under almost any conditions. For example, certain insects live in saturated salt water; others live on deserts or in hot springs.

Insects Transmit Many Important Diseases.

The role that mosquitoes play in spreading malaria, yellow fever, and elephantiasis is well known. Human lice and rat fleas spread typhus fever, tsetse flies disseminate sleeping sickness, and houseflies carry typhoid fever and cholera germs. A long list of diseases carried by insects could be added to the few given above.

Insects are also carriers of many plant diseases.

Insects Are Combated According to Their Methods of Attack.

Certain materials will destroy some insects and be of no avail against others. It has been found that insects may be divided into two classes based on their feeding habits. Those of one class, called *chewing* insects, eat the foliage, stems, and roots, while those of the other, called *sucking* insects, puncture the fruit, leaf, twigs, stems, or roots to suck the juice. Insecticides are thus classified according to the type of insect to be attacked, as *stomach* poisons and *contact* poisons. Chemicals are also used as fumigants, baits, and attractants in the warfare on insects.

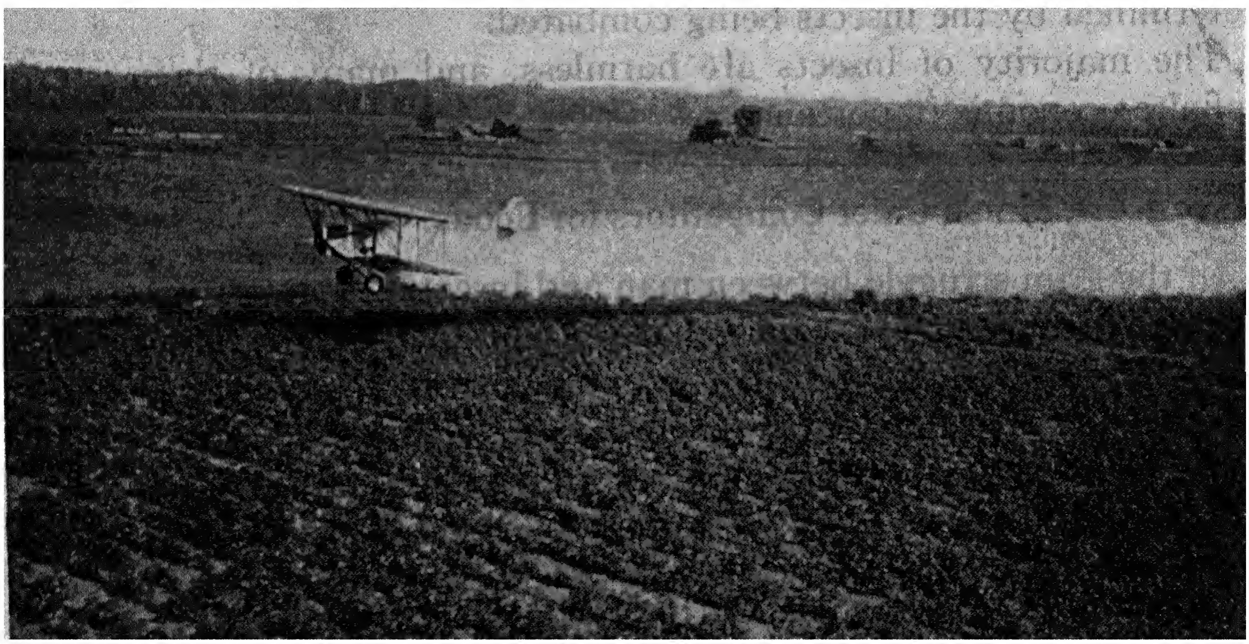


FIG. 318. Airplane dusting cotton for boll weevil control. (Courtesy of the U. S. Department of Agriculture, Bureau of Entomology and Plant Quarantine.)

Various Types of Stomach Poisons Are Used to Kill Insects.

Arsenical poisons are the most important stomach poisons. Arsenic is used in such forms as calcium arsenate, lead arsenate, basic copper arsenate, and Paris green. These products are either sprayed or dusted on the plants. Unfortunately, they leave residues on food products which have a cumulatively harmful effect on the human body, so that the chemist is now called in to determine the amounts to be used on various fruits and vegetables and to work out methods of removing the poisons before the products are marketed.[1]

The use of lead arsenate was first introduced in 1894 by *F. C. Moulton*, chemist for the Massachusetts Gypsy Moth Commission. Since that time its use has increased to millions of pounds a year.

[1] Consumers should find ways to exert pressure to compel adequate protection from poisons.

Calcium arsenate, a cheaper compound than lead arsenate, is used in huge quantities in the cotton belt, where it is dusted on by airplane to control the boll weevil. Thrips on lemon trees are successfully combated with a spray of tartar emetic.

Recently rotenone has been found to be toxic to many insects and yet not poisonous to the higher animals. In 1940, 3,220,972 pounds of Derris were imported from the East Indies, while 3,345,843 pounds of Lonchocarpus were imported from Brazil and Peru for extraction of rotenone.

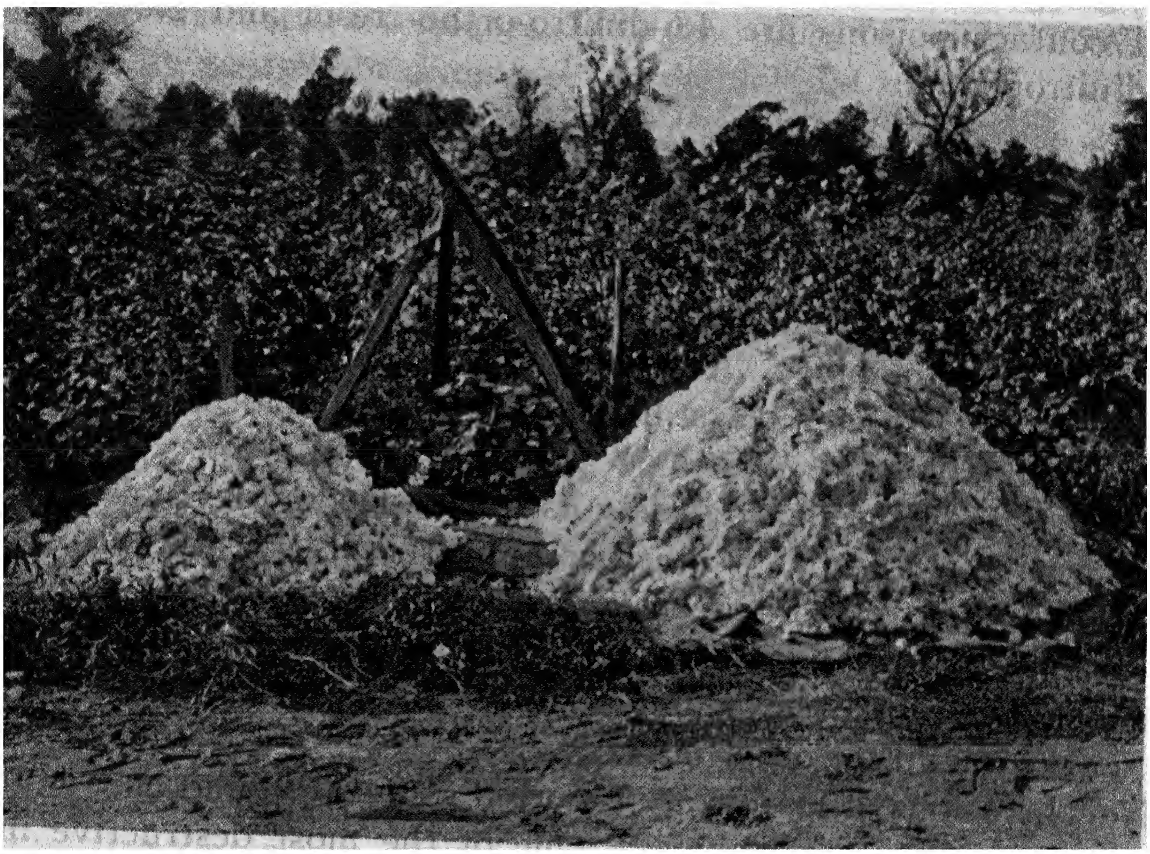


FIG. 319. Difference in yield between unpoisoned and poisoned plots. Poisoned on right. Results of boll weevil control. (Courtesy of the U. S. Department of Agriculture, Bureau of Entomology and Plant Quarantine.)

Contact Insecticides Are Familiar Today.

Common pyrethrum plants yield two chemicals that are deadly to insects but only slightly toxic, if at all, to the higher animals. Pyrethrum is one of the first substances to be successfully used as a contact insecticide. Pyrethrum powder has been known in Europe for more than a century as Dalmatian or Persian insect powder. Early in the nineteenth century, the jealously guarded secret nature of this powder became known, when an Armenian merchant observed that it was prepared from the powdered flower heads of certain plants of the genus chrysanthemum.

Over three million pounds of insect powder are used in the United States each year. In 1940 we imported 12,000,000 pounds of pyrethrum flowers. Many fly sprays consist of a solution of pyrethrins, the active ingredients of pyrethrum in a petroleum fraction similar to kerosene.

Every year about a million pounds of nicotine are extracted from waste materials of the tobacco industry for use as an insecticide. It is especially valuable as a contact insecticide in killing aphids.

Lime-sulfur spray used in the control of scale insects is prepared by boiling together a mixture of sulfur, lime, and water. Recently developed contact poisons are 4,6-dinitro-ortho-cresol and 2-cyclohexyl-4,6-dinitrophenol.

Fumigants Are Also Used to Kill Insects.

Hydrogen cyanide gas, HCN, is used to fumigate warehouses and sacked grain, although carbon disulfide is also effective for dry grain and seeds. Carbon disulfide presents a serious fire hazard because of its ready inflammability. A mixture of ethylene dichloride and carbon tetrachloride, although it is a little more expensive for this purpose, is not inflammable.

Paradichlorobenzene, so widely used as a deodorant, is also used to kill moths in clothes, as well as borers in fruit trees. Methyl bromide has been found to be an effective fumigant for the potato tuber moth, the codling moth, and the Japanese beetle, while dichlorethyl ether, ethylene dichloride, hexachloroethane, ethylene oxide, and methyl formate are used for other insects.

New invasions of insects are reported frequently, and new methods of attack are being developed. One of the most destructive insect pests is the termite, which gets into wood and eats the heart out of it before it is detected.

Insect Repellents Are Greatly Needed.

In many communities where the expense of mosquito control is too great, the home owners who have spent a great deal of money in developing and caring for their lawns and gardens would welcome an efficient repellent for mosquitoes that would permit them to enjoy warm evenings in their yards.

A few repellents have been discovered. For example, butyl oxide oxalate is a fair repellent, while tetramethyethylthiuran disulfide is an excellent repellent for the Japanese beetle.

Adult houseflies are repelled by a mixture of diethylene glycol monobutyl ether acetate and triethanolamine. A still better repellent

is a mixture of diethylene glycol monobutyl ether acetate, diethylene glycol monoethyl ether, alcohol, and corn oil. This mixture is also very repellent against mosquitoes.

Mosquitoes are also repelled by a mixture of thyme oil and pyrethrum extract in castor oil.

In the treatment of insect pests, it would often be desirable to attract insects. When insects such as the Japanese beetle or grasshoppers are to be killed in quantities of hundreds of tons, it would help a great deal if substances could be used to attract the insects into containers where they could be killed on a large scale. It has been found that *male* June beetles are attracted by isoamylamine and that Japanese beetles are attracted by geraniol or a mixture of geraniol and eugenol.

STUDY QUESTIONS

1. Discuss the methods by which man combats his insect enemies.
2. What are man's chief competitors for food?
3. What is the objection to the use of arsenic and lead poisons for spraying plants?
4. What is the active ingredient in many fly sprays?
5. List two methods other than the use of poisons for killing insects.
6. In what respects are insects superior to man?
7. What would be the advantages of substances which would attract or repel insects?
8. Why is rotenone such a valuable insecticide? Where is it obtained?
9. Prepare a list of diseases and their insect carriers.
10. Why is the promiscuous destruction of insects undesirable?
11. Would you say that insects are winning in their warfare against man?
12. Compare international wars with man's war against insect pests.

UNIT X

SECTION 5

THE UTILIZATION OF NATURALLY OCCURRING SOLUBLE SALTS HAS CONTRIBUTED MUCH TO MAN'S PHYSICAL WELFARE

Introduction.

Tremendous amounts of salts, such as sodium chloride, bromide, iodide, fluoride, sulfate, carbonate, borate, phosphates, and similar salts of potassium, magnesium, and calcium have been dissolved by water during the ages and carried to the oceans or inland seas. In some places these inland seas and portions of ancient oceans dried up to leave vast deposits of these soluble salts. These salts have found a wide variety of uses in modern civilization. Perhaps the most characteristic ones are those which are involved in man's modern emphasis on cleanliness.

Common Salt Has Played an Important Part in the History of the Human Race.

> The Romans found salt so necessary to the efficiency of their far flung armies that each soldier was provided with a special ration of it, or with the means of purchasing it. This stipend was called salarium argentum, and from it springs our English word "salary." The expression "he is not worth his salt" also traces back to this source.[1]

From time immemorial heavy taxes on salt or government monopolies have been important sources of revenue. During the Middle Ages in Europe thousands of people every year were subjected to the lash or the rack or sent to the galleys for illegal preparation of salt. It was illegal for anyone to prepare salt from sea water for his own use or even to save the water in which salt meat or fish had been cooked. The salt used in the leather industry was poisoned like our denatured alcohol is today to prevent its internal use.

Salt has never been taxed by the Government of the United States

[1] Taken from *Salt — Its Romantic History, Its Refining and Its Many Uses*, an excellent reference for a more detailed study of salt, published by the Worcester Salt Company, New York City.

and is one of our cheapest and most abundant necessities of life. Salt is obtained (1) by mining rock salt, and (2) by the evaporation of brine from the ocean or salt wells. Many large deposits of salt are widely distributed in the United States. For example, the Michigan salt beds, 32,000 square miles in area and from 1000 to 5000 feet thick, contain enough salt to supply the world for 1,000,000 years.

In addition to its use in foods, salt is used as follows: (*a*) with ice as a refrigerant, (*b*) to melt ice and snow on sidewalks and railroads, (*c*) to kill poison ivy, (*d*) in making soap, (*e*) in tanning leather, (*f*) as a flux in steel-making, (*g*) in refining of oil, gold, silver, and copper, and (*h*) as a raw material in the electrochemical industry.

The Refining of Common Salt Is a Typical Process.

The modern salt refinery utilizes methods and equipment which are almost universally employed in the refining of naturally occurring salts such as soda, borax, and potash or in the refining of such products as sugar and hundreds of other crystalline substances which are soluble in water. The steps in the refining of common salt are as follows:

a) The brine is pumped into large tanks, where lime and alum or other chemicals are added which will form gelatinous precipitates with impurities in the water. These precipitates settle out along with other suspended matter.

b) The brine is then evaporated in multiple-effect evaporators, arranged in series so that the vapor from the first evaporator is used to heat the second evaporator, etc., the boiling-point in each successive evaporator being lowered by decreasing the pressure of the atmosphere above the solutions in the successive evaporators in a stepwise fashion.

c) The salt which has crystallized in the last evaporator is separated from the mother liquor by centrifuges, in which pure water is sprayed to wash out the remaining mother liquor which contains soluble impurities. In some refining processes, an Oliver filter replaces the centrifuge. An Oliver filter is a metal drum perforated with small holes. A reduced pressure is maintained inside the drum, which thus draws the mother liquors from the salt.

d) The salt is then dried in rotary kilns.

Sometimes the salt is dissolved in water, recrystallized, filtered or centrifuged one or more times before drying, when exceptional purity is desired.

Soap Is Considered to Be a Necessity by Modern Civilization.

Soap has been used for hundreds of years. Formerly it was prepared by boiling grease or fat with the liquid obtained by leaching wood

ashes with water. Little improvement came to soap-making until the chemistry of the process became understood.

It is now known that soap is a metallic salt of certain organic acids, such as stearic, palmitic, and oleic acids. Fats and oils are compounds of these acids with glycerine (glycerine esters); and, when sodium or potassium hydroxides (caustic soda or caustic potash, $NaOH$ or KOH) react with fats, glycerine is liberated, and the soap is produced. The sodium and potassium soaps are the only important ones that are soluble in water, and for that reason these soaps alone are used for cleaning purposes. The insoluble soaps, consisting of compounds of these acids with other metals, such as calcium or magnesium, are used to prepare lubricating greases, because they enable water to be emulsified in mineral oil to form the relatively stable lubricants which we call *greases.*

The principal value of the soluble soaps is that they enable fats and greases to be emulsified by water. When the grease is removed, the dirt which clings to it is removed also. It is thought that soaps are capable of emulsifying oils because one end of the soap molecule is soluble in oils while the other end is soluble in water. Molecules of soap are then thought to form in a layer constituting a film surrounding each oil particle, in which all of the soap molecules are oriented with their water-soluble ends pointing outward.

Water-softening Is an Important Problem Today.

When soap is used with some waters, it forms insoluble curds and fails to act as a detergent. Such waters are called hard. Soft water does not produce these curds, which are insoluble soaps usually of calcium, magnesium, or iron.

There are two kinds of hard water, temporary and permanent. Temporary hardness is caused by soluble bicarbonates of calcium, magnesium, or iron, which may be changed into insoluble carbonates and thus precipitated by boiling. Permanent hardness is caused by other soluble salts of these metals, such as chlorides or sulfates. It may be removed by use of soaps; but soap is too expensive to use for softening water economically, and the curds produced are undesirable. Permanent hardness may also be removed by precipitation with sodium carbonate and lime. Some cities in hard-water regions find that it is economical to soften the whole domestic water supply by treatment with chemicals.

Many industries require an abundant supply of soft water, and the location of some industries is determined largely on this basis. Hard water not only interferes in textile, dye, and various other industries

but forms scale in boilers and pipes, which reduces their efficiency. All steam plants must therefore use soft water in their boilers. For industrial purposes and even on a small scale in the home, zeolites, sometimes called "*permutite*," are used to soften water. They are complex silicates that remove the calcium, magnesium, and iron ions and add sodium ions. The zeolites are renewed by reversing the process, which consists of passing salt water through the mineral.

Water Purification Is Also Characteristic of Modern Civilization.

Natural waters may contain objectionable suspended matter, including bacteria, as well as soluble impurities. As a general rule, the soluble materials in water, with the exception of those that cause hardness, are not objectionable. The suspended materials are usually removed by settling, or coagulation and settling, followed by filtration through sand. When coagulation is used, an iron or aluminum salt is added to water whose hydronium ion, $(H_3O)^+$, concentration has been adjusted by adding lime if necessary. These salts hydrolyze to produce gelatinous precipitates that carry down most of the finely divided suspended matter with them as they settle out. They also form a very efficient filtering layer over the sand in the sand filters which removes a large portion of the bacteria. When necessary, the remaining bacteria are then destroyed by adding very small amounts of chlorine or by treating with ozone, ultraviolet rays, silver ions, or other materials. Since 1900 the use of chlorinated water has reduced the death rate due to typhoid fever and other water-borne diseases in most of our large cities by from 80 to nearly 90 per cent. Aeration by spraying the water into the air helps to remove undesirable odors and tastes as well as to kill bacteria.

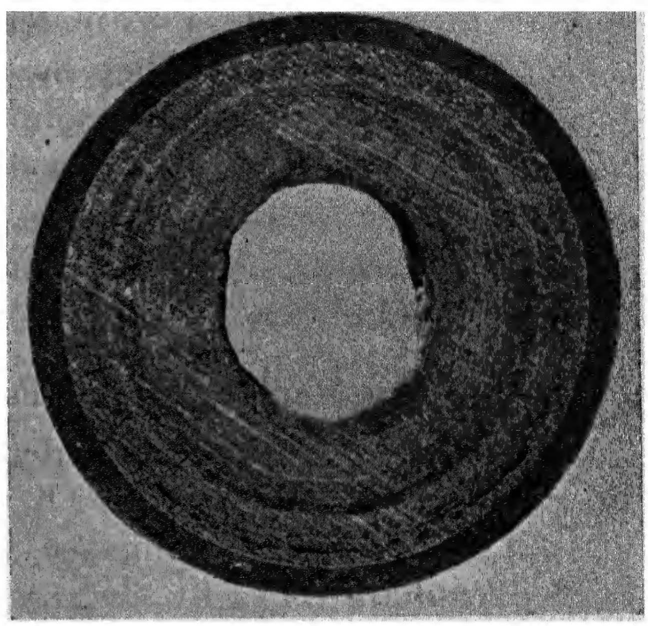


FIG. 320. Scale produced in a pipe by hard water. (Courtesy of the Permutit Company.)

Sewage is now treated so as to remove all objectionable dissolved and suspended matter and is then usually disinfected with chlorine.

Detergents and Abrasives Have Their Place in Cleanliness as Well as in Industry.

Abrasives are useful in removing films of foreign material by mechanical action. Many abrasives of different degrees of hardness are available, and it is important to select the proper abrasive for a given purpose. Powdered glass, though a good abrasive, will soon wear the enamel from the teeth when used as a constituent of a dentifrice. Certain popular abrasives that contain volcanic ash or diatomaceous earth and similar powders are frequently too coarse for continued use on enamel or porcelain.

Detergents are substances that have cleansing qualities similar to those of soaps. Sodium alkyl sulfates, such as sodium lauryl sulfate, and triethanolamine lauryl sulfate have been patented and are licensed for sale for special purposes under such names as "Drene," "Dreft," "Teel," and "Irium." They have the detergent properties of soap, but they do not form alkaline solutions and are unaffected by hardness in waters. In addition to the sodium alkyl sulfates which have been made available for domestic uses, there are fifty or more other types of "soapless soaps" which are finding wide application, especially in the textile industries.

Phosphates Are Rapidly Finding Favor in American Homes.

The known phosphate rock deposits in the United States amount to about seven billion tons. Of that amount about 9 per cent are located in Florida and Tennessee, where phosphorus is being extracted from phosphate rocks by electrochemical methods at Muscle Shoals Dam by the T.V.A. Nearly 91 per cent of the phosphate deposits are located in the western states, Idaho, Montana, Utah, and Wyoming. These western deposits are being utilized to a small extent only, partly because of the high cost of transportation, but largely because the underground mining methods required to work these deposits are more expensive than the surface mining methods used in Florida and Tennessee.

The most important use of phosphates is in fertilizers, but three sodium phosphates are coming into wide use in industry and in the homes of the United States.

1. Trisodium Phosphate. Trisodium phosphate, $Na_3PO_4 \cdot 12\,H_2O$, hydrolyzes to produce a solution which is more strongly basic than soap but not as strongly basic as lye. This salt is the cheapest of the sodium phosphates and is used for cleaning operations such as washing dishes or cleaning sinks and tubs, where a moderately strong alkali will do no harm.

2. Sodium Pyrophosphate. This salt, $Na_4P_2O_7$, is often used as a substitute for sodium hexametaphosphate because it is cheaper. It hydrolyzes to produce a mildly alkaline solution and may be used in washing even the most delicate fabrics such as silks and woolens. Sodium pyrophosphate is used with soap because it not only acts as an excellent detergent but it also prevents the formation of insoluble soaps, thus softening hard water. Several commercial soap powders contain this salt. It is used for dispersing clay in such applications as treatment of oil-well mud, in dairy cleaning because of its excellent emulsifying action on casein and butter fat, in cleaning textiles, and in the preparation of stable asphalt emulsions.

3. Sodium Hexametaphosphate. Sodium hexametaphosphate, $(NaPO_3)_6$, is a patented chemical which is licensed for sale for a wide variety of specialized uses under different names. Under the name of "Calgon," sodium hexametaphosphate is sold for washing operations. It represents one of the few major contributions to the science of washing. Its rapid and widespread acceptance by laundries, restaurants, and critical housewives, despite its relatively high price, is based on the fact that it combines with calcium and magnesium ions to form complex ions that will not precipitate with soluble soaps. "Calgon" will also dissolve insoluble soap precipitates. It is much more efficient than sodium pyrophosphate as a water-softener. For the average hard water, less than a tablespoonful of "Calgon" per gallon is required. It is especially useful as a bath salt and as a hair rinse.

Sodium hexametaphosphate will find wide application in many other fields of usefulness as its interesting properties come to be better known; for example, it is used in the treatment of burns because of its tanning action on albuminous materials. It has a strong healing action on such skin irritations as poison oak, poison ivy, sunburn, and athlete's foot. Sodium hexametaphosphate in concentrations of 0.5 to 5 parts per million has a marked inhibitive action on the corrosion of iron and steel by water. Sodium hexametaphosphate is also used in the treatment of boiler waters to prevent the formation of boiler scale, in photography, in pharmaceutical and cosmetic preparations such as toothpaste, and in insecticide sprays.

The Development of the Borax Industry Is a Story Worth Telling.

When borax was first discovered in some of the salt flats of the deserts of California and Nevada, its high price made it very much worth while to work small deposits; but these deposits were soon exhausted. Then borax was discovered in Death Valley, where it was obtained by leaching it out of the salt deposits scraped up from the

floor of the valley, crystallized, and shipped by the famous twenty-mule wagons. Rich veins of colmanite, calcium borate, discovered in the Funeral range of mountains on the east side of Death Valley, soon replaced other sources; and large mines were operated at Ryan for several years, until a still richer and more accessible deposit of borax was discovered near Kramer in the Mojave Desert. This deposit of kernite, *i.e.*, borax containing less water than ordinary borax contains in its crystals, is 4 miles long, 1 mile wide, and 100 feet thick.

In the meantime, however, a new source of borax was developed at Searles Lake, a veritable chemical treasure chest west of Death Valley and separated from it by the Panamint mountains.

During the World War of 1914–1918, the price of potash rose from $33 to $500 a ton because shipments of potash from the great German Stassfurt potash beds were cut off. Stimulated by the demand for potash, several plants were built to obtain potash from Searles Lake. One of these plants later became the American Potash and Chemical Corporation. The present huge $20,000,000 plant of this company at Searles Lake was built upon extensive research of the highest order. Today this plant produces over one half of the world's production of borax as a by-product of its potash production. It is the main source of lithium salts in the United States and produces large quantities of sodium carbonate, sodium sulfate, and bromine. A continuous research program promises additional developments.

Borax is used in the home as a mild detergent, while it is used in industry chiefly in the production of porcelain enamels such as are found in bathtubs and in the production of Pyrex glass.

The Dow Chemical Company Is a Good Example of an Electrochemical Industry.

In 1887, while a student at Case School of Applied Science, *Herbert Dow* invented a new and much less costly process for extracting bromine from brine. Two years later he began the separation of bromine by the electrolysis of the bromine-rich brines of Midland, Michigan, in a small flour-mill shed. Within a few years he also produced chlorine and sodium hydroxide by the electrolysis of the above brines by the reaction:

$$\underset{\text{sodium chloride}}{2\,NaCl} + \underset{\text{water}}{2\,H_2O} \longrightarrow \underset{\text{sodium hydroxide}}{2\,NaOH} + \underset{\text{hydrogen}}{H_2} + \underset{\text{chlorine}}{Cl_2}$$

Seeking new outlets for chlorine, the young company then combined it with sulfur to form sulfur chloride, which was then treated with carbon disulfide, CS_2, to produce carbon tetrachloride, CCl_4, an

important solvent and fire-extinguishing material. Carbon tetrachloride was then treated with iron in the presence of water to produce chloroform, a widely used anaesthetic, solvent, and organic intermediate.

The above reaction by which carbon tetrachloride was synthesized, which was the first important synthetic organic reaction to be carried out on a commercial scale in the United States, was but the forerunner of many synthetic organic chemicals to be manufactured by this company. One of the earliest and greatest achievements was the synthesis of indigo in 1916. Today the Dow Chemical Company manufactures about thirty dyes.

As the Dow Chemical Company increased in size, the distribution of its products became so widespread that it became desirable to add units to produce products at strategic locations so as to decrease transportation costs. For example, one of the latest mergers was the joining of the Great Western Electrochemical Company of Pittsburg, California, with the Dow Chemical Company on January 1, 1939.

The Great Western Electrochemical Company was started during the World War of 1914–1918 to produce chlorine by the electrolysis of sodium chloride obtained by the evaporation of ocean water in the salt flats of the San Francisco Bay region. The main products of this reaction are hydrogen, chlorine, and sodium hydroxide. At this plant hydrogen is obtained in larger quantities than can be marketed. A portion of the hydrogen is combined with chlorine to produce hydrochloric acid, HCl. Another portion is burned in air to remove the oxygen, thus leaving nitrogen which is combined by the Haber process with more hydrogen to form ammonia, NH_3. The ammonia is now liquefied and sold in cylinders, or combined with water to produce ammonium hydroxide, NH_4OH, or with chlorine to produce ammonium chloride, NH_4Cl, to the extent that there are sales for these products.

A portion of the chlorine produced as the main product of this plant is liquefied and sold in cylinders for purifying water and bleaching paper, while other portions of chlorine are caused to react with iron or zinc to form chlorides of these metals, with benzene to produce the deodorant, paradichlorobenzene, $C_6H_4Cl_2$, and with hydrocarbons of natural gas to produce hexachlorethane, methylene chloride, and perchlorethylene. This branch of the Dow Chemical Company uses more electricity than the entire city of Berkeley, which has a population of approximately 100,000.[1]

[1] The chlorine industry of the United States alone consumes over two billion kilowatt hours of electricity per year. The annual production of chlorine is equivalent to 17,000 tank cars, each holding 30 tons.

From the brines of the salt wells at Midland, Michigan, both calcium and magnesium chlorides are produced. Calcium chloride (Dow-flake) is used to lay dust because it absorbs water from the atmosphere.

The Dow Chemical Company built a huge plant in which chlorine is combined with benzene to produce chlorobenzene. From chlorobenzene the important chemical, phenol, is prepared. With plenty of phenol at hand, it was logical to prepare the phenol derivatives, aspirin and synthetic oil of wintergreen. Aniline was also produced from chlorobenzene. Dyes and pharmaceuticals logically followed from these materials, until the Dow Chemical Company had close to 400 products in commercial manufacture in 1941. Its large research expenditure ($7,000,000 in 1941) should result in the addition of other important products from time to time.

In 1933 the Dow Chemical Company, finding its salt wells in Michigan too limited, started a new plant at Wilmington, North Carolina, where it produces over 100,000 pounds of bromine per day from ocean water, for use in ethyl gasoline.

Later the Dow Chemical Company built a plant at Long Beach, California, to remove the iodine from the waste oil-well brines, so that today a substantial proportion of the iodine requirements of the nation is supplied by this plant.

The Dow Chemical Company has recently branched out into the production of cellulose products such as synthetic plastics, lacquers, fibers, films, paints, enamels, and other products.

One of the Company's largest tonnage products is magnesium, which is sold as a strong light alloy (Dowmetal) for airplanes, etc.

In 1940, a $15,000,000 plant for the production of magnesium from ocean water was completed.

Such is the story of the outgrowth of a student's investigation of the electrolysis of naturally occurring soluble salts to a company of over 7000 employees.

Some of Our Best Disinfectants Are Produced from Naturally Occurring Soluble Salts.

It has already been pointed out that chlorine is obtained by the electrolysis of sodium chloride. Chlorine itself is a powerful disinfectant and is used, as already mentioned, in the disinfection of water. It is also combined with lime to form bleaching powder, $CaOCl_2$, which may be used for the same purpose when chlorine is not available.

Chlorine will react with sodium hydroxide (also obtained in the electrolysis of sodium chloride) or with sodium carbonate to produce

sodium hypochlorite, which sells as a 5 per cent solution in water under many names, such as "Clorox," "Purex," "Zonite," etc. This solution is one of the most powerful of all the disinfectants and one of the least harmful to the delicate tissues. It is widely used under various fanciful names for use in disinfecting utensils in the dairy industry. Because of its bleaching action it is also valuable in laundry work.

The use of hypochlorites as disinfectants dates from World War I, when Dakin's solution, prepared by the action of chlorine on sodium carbonate with the addition of a little boric acid, was the answer of Science to the call of military surgecns for a disinfectant to stop the tremendous loss of life due to infections.

Incidentally, the use of chlorine as a war gas or as a constituent of other war gases saved many more thousands of lives because it disabled many soldiers so that they had to be taken to hospitals where they were in less danger of being blown to pieces by the shells of the enemy.

Bromine and iodine, two other active nonmetals belonging to the same periodic family called the *halogen* family, are present in sea water. Bromine is obtained directly from sea water or from certain salt wells, but it is not used extensively as a disinfectant, although hypobromites are excellent disinfectants and bromine may be substituted for chlorine for use in disinfecting water. Iodine is still one of the best disinfectants, and the ordinary solution of iodine in alcohol, called tincture of iodine, is familiar to nearly everyone. Iodine may be obtained from seaweeds, the Chilean nitrate deposits, or petroleum brines as mentioned above.

The lightest and most active halogen is the greenish-yellow gas, fluorine. A few of its compounds hydrolyze to produce hydrofluoric acid, which is destructive to animal life. Such compounds are therefore a frequent ingredient of insect and ant powders, and they are also poisonous to human beings. The chief use of fluorine and hydrofluoric acid is in etching glass, inasmuch as fluorine reacts with glass to form a soluble compound, silicon tetrafluoride.

STUDY QUESTIONS

1. Discuss *soap* as to (*a*) what it is, (*b*) how it is made, (*c*) kinds of soap, and (*d*) what it is used for.
2. Discuss *hardness of water* as to (*a*) kind of hardness, (*b*) how it is removed, and (*c*) why it is objectionable.
3. Discuss *the purification of water* as to (*a*) the types of impurities that are objectionable for different purposes, and (*b*) how these impurities are removed.
4. Discuss *abrasives* as to (*a*) what an abrasive is, (*b*) naturally occurring abrasives and their uses, and (*c*) artificial abrasives and their uses.

5. What is "Clorox"? Under what other names is this substance sold? How is it prepared? For what purpose is it used?
6. Why is glycerine a by-product of the soap industry?
7. What is the general composition of greases used for lubricating automobiles?
8. How do soaps remove dirt from clothes in the laundering process?
9. What is a detergent? Give an example. Why do detergents have detergent properties?
10. Name three members of the halogen family of elements, and give their sources and uses.
11. Show how a large chemical industry is the logical outgrowth of the electrolysis of common salt.
12. What products are now obtained on a large scale from ocean water?
13. Discuss the use of the three phosphates in the home. What factors determine the use of each?
14. What are the advantages of "soapless soaps"?
15. Discuss the occurrence and uses of borax.

world-wide stable organization of society. At the present stage of human culture a stable social organization is absolutely essential to personal welfare; such a stable organization depends upon the development of relationships which are mutually advantageous; exploitation, like slavery, cannot exist in such a society. This stable society should represent a dynamic, rather than a static, equilibrium. Change is essential to progress, and society must be so organized that change and variety which results from change may be free to develop.

Technology, in Creating Social Benefits, Has Also Created Social Problems.

Technology has given us lower prices, improved quality, higher wages, a shorter work-week, less child labor, a fuller utilization of natural resources, increased leisure, a broader basis for a higher standard of living, increased interdependence, increased centralization of economic and political controls, and greater *opportunity* to create a stable civilization.

Among the problems created by technology are the obsolescence of certain occupations, the loss of handicraft artistry, recurrent business depressions, wastes of monopolistic competition and unemployment, and the increased destructiveness of war.

The Distribution of the Wealth Produced by Science Must Be Organized.

> For a generation and more past, the center of human interest has been moving from the point which it occupied for some four hundred years to a new point which it bids fair to occupy for a time equally long. The shift in the position of the center of gravity in human interest has been from politics to economics; from considerations that had to do with the forms of government, with the establishment and protection of individual liberty, to considerations that have to do with production, distribution, and consumption of wealth.[1]

In 1940 North China was experiencing one of the worst famines of the century; in the same year the United States' carry-over of wheat amounted to six hundred million bushels, which is twice the amount that we consume in a year.

Organizing ability is a characteristic of the American people. We have labor unions, teachers' associations, medical associations, automobile dealers' associations, farmers' associations, manufacturers' associations, employers' groups, and distributors' organizations. Each of these economic organizations is determined to get its share of the national wealth for its own members. If other people lose out, then

[1] N. M. Butler.

it is up to them to organize, and so even the relief workers and the WPA workers find it necessary to organize and pool their "strength." Our country is run by pressure groups, and our votes are too often controlled by the interests of the pressure groups to which we belong.

Under the above system of large-scale "rugged individualism," dire poverty walks hand in hand with the most extravagant living the world has ever known; overproduction is accompanied by under-consumption. We are literally whimpering in wealth, crying because we are hungry because there is too much food. Can we bring the machine under the control of society? Can we organize our means of production and distribution and still maintain the freedom of thought and action that are essential to scientific research and to democracy? Do we have to follow the footsteps of Russia or Germany in order to bring about planned production and distribution? Must we sacrifice all other values in order to obtain economic security, and if so, would it be worth while to do so? We can and must organize in such a way that clever foreign propagandists will not be able to attack us at our weakest point by playing one pressure group against another, thus interfering with production and distribution and weakening our national unity.

The Government in the United States Is Experimenting with the Problems of Distribution.

For the ten-year period 1918–1928, the wealthiest 10 per cent of the population received an average of 33 per cent of the total income, but since that time graduated income taxes and excess-profits taxes have changed this picture; the wealthiest 10 per cent still get as much money, but they do not keep as much of it as they did twenty years ago. The government has taken the money from rich individuals and corporations and has borrowed billions of dollars to provide work, food, clothing, and housing for the unemployed people.

The United States Government has sought to gain control of the marketing of stocks and bonds and of banking. It has made loans available to farmers and home-builders at reasonable interest rates. It has developed recreational programs, recreational areas, and national monuments and parks to replace commercialized recreation. It has made education available to the masses through the greatest system of public schools the world has ever known, supplemented by special instruction by the C.C.C. and N.Y.A. organizations which reach young people not reached by other educational institutions.

The United States Government is no longer chiefly engaged in keeping order at home and defending the nation against foreign foes;

today it is recognized that its chief function is the promotion of the well-being of its citizens. It is not only concerned with the control of banking, credit, and tariff, but also with the conservation of natural resources, service to business, assistance to agriculture, safety of workers, regulation of public utilities, unemployment, old-age and accident insurance. Many experiments have been failures, but such tremendous progress has been made that one is justified in the belief that *Democracy* can solve the problems of production and that *Democracy* can make possible economic security and still maintain the values of truth, beauty, goodness, and all of the other values that may be summed up under the word, *freedom.*

Warfare Is a Symptom of Disorganized Society.

At the time this Section is written, the world is witnessing a tremendously destructive conflict. This war is even more than a war to obtain or retain raw materials and markets. In 1941 this war appeared to be a titanic struggle to organize the whole world under one strong government.

Victor L. Berger gives a picture of the total financial cost to the world of the World War of 1914–1918 as follows:

> . . . According to the best statistics obtainable, the World War cost . . . $400,000,000,000 in property. In order to give some idea what this means, just let me illustrate it in the following: With that amount we could have built a $2500 house and furnished this house with $1000 worth of furniture and placed it on five acres of land worth $100 an acre, and given all this to each and every family in the United States of America, Canada, Australia, England, Wales, Ireland, Scotland, France, Belgium, Germany, and Russia. After doing this there would be enough money left to give each city of 200,000 inhabitants and over in all of the countries named, a $5,000,000 library, a $5,000,000 hospital, and a $10,000,000 university. And then, out of the balance we could still have sufficient money to set aside a sum at 5% interest which would pay for all time to come a $1000 yearly salary for each of an army of 125,000 teachers and, in addition to this, to pay the same salary to each of an army of 125,000 nurses. And, after having done all this, we could still have enough left out of our $400,000,000,000 to buy up all France and Belgium and everything of value that France and Belgium possess; that is, every French and Belgian farm, home, factory, church, railroad, streetcar — in fact, everything of value in these two countries in 1914. . . .

The United States Government spent $22,000,000,000 in World War I. This amount was equal to the total cost of the United States Government from 1791 to 1914. In the one year of June, 1940, to June, 1941, however, more than $50,000,000,000 was appropriated for national defense and this was eclipsed by still larger appropriations after "Pearl Harbor."

According to the Swedish Society for the Study of the Social Consequences of World War I, the total cost in human lives must be estimated at 40,000,000. What these figures represent in lost genius, crippled bodies, suffering, and misery cannot be expressed. To this terrific cost must be added the legacy of hate which twenty years later bore the fruits of another deadly world conflict.

This increasing cost of war can be attributed to Science. The modern age of industrialism and technology is the direct outgrowth of the impact of Science on civilization. These revolutionary forces have brought about economic warfare in the competition for raw materials and markets, thus sowing the seeds of warfare. The ruling motive of so many people of this age, that of profit at any cost, has been demonstrated by the actions of powerful international munitions-makers in fomenting war. At the same time Science, through technology, has furnished the machines of war and has made it possible to engage whole nations, soldiers and civilians, including women and children, in more deadly conflict than ever before. Science has also made it possible to bring about these terrible losses in a very short time.

Conclusion.

Science is equally important in war and peace. It provides means to kill or save the lives of mankind. It provides such weapons as hydrogen cyanide gas and electrocution to destroy harmful bacteria and insects, which are likewise used to put men to death. It provides explosives for great public works, agriculture, and mining; and yet these explosives may be used to destroy what man has created. Science provides man with greater possibilities for good and for evil than he has ever before realized, but Science has nothing to do with the choice between these motives. It merely makes the decision a more important and more pressing problem. Brotherly love and understanding are not merely desirable; they have been made necessary for the survival of civilization. The question is whether man's moral, ethical, or religious progress can keep up with his scientific progress.

If these problems of humanity created by Science can be properly solved, this will be but another achievement of Science. It is believed by many people that the same method that was used to bring about the changes that caused these problems can also be used to solve them. Today such sciences as economics, sociology, and political science represent man's attempt to utilize the scientific method in the field of human relations. Social religion still furnishes the motive; but here, as in the other problems of man, Science must furnish the method.

STUDY QUESTIONS

1. Criticize the statement, "The world would be better off if scientific research were discontinued for a time."
2. In what respects may it be said that the power of Science is poorly directed and imperfectly used by society today?
3. How can one insure that the power of Science is used for the welfare of man?
4. Robert A. Millikan predicted that "life fifty or a hundred years hence is not — barring a collapse of civilization — likely to differ nearly as much from the life to-day as this life differs from that of even half a century ago." Mark Sullivan said: "The things to come will probably be more marvelous and more numerous than those that have already arrived. For as to any kind of invention, there is a kind of law of geometrical progress."

   Which of the above statements seems most likely to be true to you? Which statement is probably truest for (*a*) the physical sciences, (*b*) the biological sciences, (*c*) the social sciences?
5. In what respects is the "fifth wheel" of an automobile the most important one?
6. Why is modern society an unstable equilibrium?
7. What have been the benefits of technology?
8. What problems have been created by technology?
9. What factors have been responsible for the distribution of wealth in the United States up until the past ten years?
10. Why have various groups of laborers and business men been organized in the United States?
11. List the experiments of the National Government in regional and national planning during the past decade.
12. List the achievements which have been accomplished under our democratic way of life.
13. What are the causes of war?
14. What were the expressed war aims of the democracies and the totalitarian states in World War II?
15. Discuss the cost of warfare to civilization.
16. Discuss the relative merits of the totalitarian and democratic approaches to the establishment of a lasting world-peace.

CONCLUSION

You have just completed the story of the development of physical science and can now appreciate in a small way at least the methods by which it has been accomplished and the effect it has had and will have on the life of man in his physical world. You have become familiar, in a general way at least, with the fundamental laws and theories of physical science.

Supergalaxies, stars, planets, comets, meteors, atoms, molecules, protons, electrons — what a world has been revealed to us! But the picture is incomplete, and the true scientist hopes that there will always be new worlds to conquer.

Physical science has wrought great changes in the life of mankind. For the most part these changes represent genuine progress. Physical science properly coordinated and controlled offers vast possibilities for even greater progress. On the other hand, the rise of industrialism and technology has not been entirely beneficial to mankind. International, race, and class conflicts for economic advantages have become increasingly more serious, and individual insecurity has become widespread.

Chaos, confusion, and bewilderment abound. The material foundations of inherited modes of living and moral conceptions which have been cherished for generations have been destroyed. The American people consequently face an enormous task of mental, as well as institutional, reconstruction. Physical science has been a prominent cause of this revolution. The same method that has created these modern problems can solve them when controlled by the proper motive.

Social and economic problems are now more pressing than any purely scientific problem. Everyone who expects to live intelligently in this scientific age, helping to solve its problems, needs to appreciate and utilize the scientific method as far as possible. Someone has compared the scientist to the busy bees and the fruits of Science to the honey produced by the bees. There must be a hive and a beekeeper who understands the requirements and nature of the bees. An ever increasing number of people are joining the ever expanding fields of Science, and it is hoped that some of you who have had this brief glimpse into its possibilities will decide to join the ranks of the busy bees. The

majority of students, however, who have read this book will be found among the future beekeepers. If these students have come to see that the future development of mankind depends upon their intelligent appreciation and their cooperation with and support of the scientist, their time has been well spent.

The important feature of Science, that is, the feature that makes Science important enough to be included in general education, is its attitude and methodology. It is this spirit of inquiry and this critical scrutiny that have made possible the great achievements studied in this text. President J. R. Angell pointed out in a recent address, "It is unwarranted flattery to call ours the age of Science." When it is dark enough one can see the stars. Science has thus far just intensified the darkness. Only the first word of the story of Science in the service of man has been written.

In this course you have seen how the method of Science leads to knowledge. It is hoped that you have formed a lifelong habit of approaching every problem from a scientific viewpoint. Ways and means must be found to continue the study of Science during the rest of your life. In fact, this text is intended to be merely the introduction to this lifelong study.

You will find it fascinating to have some scientific hobby. Photography, especially the new color photography, integrates Science and art in a way that grips many people. Other people find that their lives are enriched by collecting minerals, radio tubes, phonograph records, flowers, and a host of other things which are not only fun to collect but even more fun to know about.

You can have some wonderful times as you maintain the spirit of inquiry and the habit of scrutiny in all of life's activities. A visit from a vacuum-cleaner salesman can change from a boresome hour to a fine opportunity to practice the art of asking why and demanding proof of statements. The problem of buying insurance can furnish real intellectual enjoyment if you approach it scientifically. You will be surprised how entertaining it is to sit down and analyze your insurance needs. You will be surprised when you discover how much money you can save by buying what you want without paying for anything which is not essential to your program of insurance.

The selection of a dentist, physician, lawyer, or auto mechanic presents a challenge to the scientific mind. The selection of food and its preparation can well become an intellectual activity that will continue throughout life; at the same time, it may serve to lengthen that life.

Whether you are confronted with the purchase of an automobile, the building of a house, the treatment of a serious illness in your family,

or the everyday problems of your vocation, the scientific approach will yield real satisfactions and values. Furthermore, you will be a better citizen.

You have not "had" a course in physical science, but rather you have just started a lifetime attitude and habit. Continue your interest and your readings in the world of physical science, and some day you will look back on this course as one of the great opportunities of your life.

Remember that, regardless of the mark in the registrar's office, your grade in this course depends, not on what you have done, but on what you *will* do as a result of taking this course. Would it not be a splendid idea to send in your grade to your teacher every year for the next ten years?

A FINAL COMPREHENSIVE STUDY QUESTION

List the major scientific discoveries of the past century in each of the fields of physical science and indicate as far as possible what influence these have had on man's religious thought, social life, politics, economic status, and mental outlook.

And step by step, since time began,
I see the steady gain of Man.

— Whittier.

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Brauer, O. L.	*Chemistry and Its Wonders*	American Book Co.	1938

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Furnas, C. C.	*The Storehouse of Civilization*	Teachers' College, Columbia University	1939
Glasscock, C. B.	*Then Came Oil*	Bobbs-Merrill Co.	1938
Grady, Roy	*The Chemist at Work*	Journal of Chemical Education	1939
Holmes, H. N.	*Out of the Test Tube*	Emerson Books, Inc.	1937
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Jaffe, B.	*Crucibles*	Simon & Schuster, Inc.	1930
Nettleton, L. L.	*Geophysical Prospecting for Oil*	McGraw-Hill Book Co.	1940
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Bauer, W. W.	*Americans, Live Longer!*	Bobbs-Merrill Co.	1940
Bauer, W. W.	*Health, Hygiene, and Hooey*	Bobbs-Merrill Co.	1938
Bernheim, B. M.	*Medicine at the Crossroads*	William Morrow & Co.	1939
Borssook, H.	*Vitamins, What They Are and How They Can Benefit You*	The Viking Press	1940
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Cummings, R. D.	*The American and His Food*	University of Chicago Press	1940
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Fülop-Miller, R.	*Triumph Over Pain*	Bobbs-Merrill Co.	1938
Gerber, S. R.	*Alcohol and Traffic*	Better Books Press	1939
Gericke, W. F.	*The Complete Guide to Soilless Gardening*	Prentice-Hall, Inc.	1940
Gisvold, O., and Rogers, C. H.	*The Chemistry of Plant Constituents*	Burgess Publishing Co.	1939

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Gruenberg, B. C., and Unzicker, S. P.	*Science in Our Lives*	World Book Co.	1938
Gustafson, A. F.	*Handbook of Fertilizers*	Orange Judd Pub. Co., Inc.	1939
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Harpole, J.	*Behind the Surgeon's Mask*	Frederick A. Stokes Co.	1940
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Hegner, R.	*Big Fleas Have Little Fleas*	Williams & Wilkins Co.	1938
Heiser, V.	*An American Doctor's Odyssey*	W. W. Norton & Co.	1936
Hertzler, A. E.	*The Horse and Buggy Doctor*	Harper & Brothers	1938
Hill, J.	*Germs and the Man*	G. P. Putnam's Sons	1940
Hoogstraal, H.	*Insects and Their Stories*	Thomas Y. Crowell Co.	1941
Howard, L. O.	*The Insect Menace*	D. Appleton-Century Co.	1933
Howe, H. E.	*Chemistry in Agriculture*	Chem. Foundation, Inc.	1931
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Jerger, J. A.	*Doctor — Here's Your Hat!*	Prentice-Hall, Inc.	1939
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Krynine, D. P.	*Soil Mechanics*	McGraw-Hill Book Co.	1941
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Macartney, W. N.	*Fifty Years a Country Doctor*	E. P. Dutton & Co.	1938
Marshall, E. K., *et al.*	*Chemotherapy*	University of Pennsylvania	1941
Metcalf, C. L., and Flint, W. P.	*Insects (Man's Chief Competitors)*	Williams & Wilkins Co.	1932
Montague, J. F., M.D.	*Broadway Stomach*	Simon & Schuster, Inc.	1940
Nixon, R. B.	*Corner Druggist*	Prentice-Hall, Inc.	1940
Sava, G.	*The Healing Knife*	Harcourt, Brace & Co.	1938
Silverman, M.	*Magic in a Bottle*	The Macmillan Co.	1941

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Udmark, J. A.	*The Road We Have Covered*	Modern Age Books	1940
Vaughan, W. F.	*Strange Malady*	Doubleday, Doran & Co.	1940
Waddington, C. H.	*Organizers and Genes*	The Macmillan Co.	1940
Walton, R. P.	*Marihuana, America's New Drug Problem*	J. B. Lippincott Co.	1938
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